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PAPERS AND DISCUSSIONS

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THIRD PROGRESS REPORT OF THE SPECIAL COMMITTEE TO REPORT ON STRESSES IN RAILROAD TRACK*

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November 29th, 1922

* Presented to the Annual Meeting, January 17th, 1923.

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TO THE AMERICAN SOCIETY OF CIVIL ENGINEERS:

The Special Committee to Report on Stresses in Railroad Track herewith presents its third progress report.

I.—INTRODUCTION

1.—Preliminary.—Since its organization in 1914, the Committee has been co-operating with the Special Committee on Stresses in Railroad Track appointed by the American Railway Engineering Association, the membership of the two committees being the same with the exception of one member of the American Railway Engineering Association who does not hold membership in the American Society of Civil Engineers, and the work has been carried on as that of one committee. This report is presented simultaneously to the two Societies and to the American Railway Association, which also has been co-operating in the work for the past four years.

As stated in the earlier reports, the Committee has felt that an adequate report on stresses in railroad track must be based largely on experimental data derived from extensive tests on standard railroad track, and that, in view of the complexity of the action of track under load and the variability of the conditions to be found in track and load, the work of conducting experiments and reducing the data would necessarily require much time and effort. The development of methods of conducting the tests and the work of devising the instruments and apparatus have involved a considerable expenditure of time, effort, and money. It has been recognized that in obtaining data on the action of track under variable conditions of both track and load, great refinement of method was not possible and that it was important to make tests under conditions of railroad service as nearly normal as possible, also utilizing of course the data of laboratory investigations where conditions would not warrant satisfactory experiments in the field.

The first progress report of the Committee was published in Vol. LXXXII of the *Transactions* of the Society (1918). It may also be found in Vol. 19 of the *Proceedings* of the American Railway Engineering Association (1918). In this report, a method of analysis for determining the moments and stresses in the rail by considering the track as an elastic structure was presented, the instruments and methods of testing were described, the depression of the track and the rail profile under load were given, and the stresses developed in the rail under a variety of loads were recorded. The report relates principally to stresses in rail and to the general elastic conditions of the track.

The second progress report of the Committee was published by the Society in Vol. LXXXIII of *Transactions* (1919-20) and in *Proceedings* for February, 1920. It may also be found in Vol. 21 of the *Proceedings* of the American Railway Engineering Association, in *Bulletin 224* of the Association, and in *Circular No. S-II-10* of the American Railway Association. This report gives the results of tests on two railroads, with several types of locomotives, to determine the stresses in rail in relation to speed and counterbalance effect.

It records the results of tests on two railroads to determine the depression of track and the flexure of ties and their action under load for a variety of conditions found in track. Tests to find the manner and the principles involved in the transmission of pressure from one or more ties downward and laterally through ballast material were reported and an analytical consideration of the transmission of pressure was given.

The work reported herein includes tests on straight track and curved track. In the tests on straight track, consideration was given to the effect of counterbalance, the effect of speed and the combined effect of speed and counterbalance, and the lateral bending moments and stresses in the rail. In the tests on curved track are taken up the general action of curved track as the locomotive traverses the curve, the magnitude of the vertical bending stresses in the rail and the corresponding vertical loads producing them as contrasted with the normal loads, the lateral bending moments and stresses under the several wheels, the distortion of the alignment of the curves, and the general effect of speed, degree of curve, and super-elevation. The tests were conducted on the Illinois Central Railroad, the Delaware, Lackawanna and Western Railroad, the Atchison, Topeka and Santa Fe Railway, and the Southern Pacific Railroad. In the tests, thirteen locomotives of eight distinct types were used. In several types, there were variations in the design of the locomotives of the different railroads. The report is presented under the heads of Tests on Straight Track and Tests on Curved Track.

The Committee is continuing work on the subject assigned to it.

2.—Acknowledgment.—Since the second progress report was issued, the funds for use in carrying on the work of the Committee have been taken principally from contributions made by the American Railway Association. The Committee expresses its appreciation of this support. Expenditures have also been made from funds in the hands of the American Society of Civil Engineers and the American Railway Engineering Association contributed by the United States Steel Corporation, the Bethlehem Steel Company, the Lackawanna Steel Company, and the Cambria Steel Company.

The co-operation of railroad companies in furnishing facilities for the test work has itself been a large contribution. The Illinois Central Railroad the late A. S. Baldwin, M. Am. Soc. C. E., Vice-President, and F. L. Thompson, Chief Engineer; the Delaware, Lackawanna and Western Railroad, G. J. Ray, M. Am. Soc. C. E., Chief Engineer, and A. J. Neafie, Principal Assistant Engineer; and the Atchison, Topeka and Santa Fe Railway, C. F. W. Felt, M. Am. Soc. C. E., Chief Engineer, have been liberal in providing locomotives, track, and other facilities in the conduct of the tests. The Atchison, Topeka and Santa Fe Railway and the Southern Pacific Company have also made it possible for the Committee to use such portions of the results of the tests made on the lines in California as are related to the subject matter of this report. A number of engineers from the Engineering, Mechanical, and Test Departments of the Atchison, Topeka and Santa Fe Railway gave helpful assistance throughout the work. The services of Mr. C. C. Huycke in aiding in the reduction of the data were also contributed.

Mr. E. E. Cress, Assistant Engineer of Tests, in charge of field and office work and the reduction of data and preparation of material, is entitled to much credit; his thorough familiarity with details, keen grasp of the problem, and helpfulness in the study and preparation of the data have made his services particularly valuable. Louis J. Larson, Jun. Am. Soc. C. E., Associate in Theoretical and Applied Mechanics in the University of Illinois, by reason of his special training and insight in testing work, has given valuable service in both laboratory and field work during the summer seasons. Messrs. H. L. Parr and R. Ferguson have given helpful service in the reduction of data and the preparation of the report. Others have assisted in the work from time to time and all have given loyal and careful service.

The University of Illinois has continued to co-operate in the work by giving the use of laboratory, shop, and office facilities, and through the service of members of the staff of the Engineering Experiment Station from time to time.

The Committee records with profound regret the loss of a member by death, Mr. Archibald Stuart Baldwin, who from the time of the organization of the Committee took great interest in the work and was active in the making of plans, the provision of means for carrying on the tests, and the discussion and interpretation of the results. He was especially helpful in making the arrangements for the extended use of locomotives and track of the Illinois Central Railroad for test work.

TABLE 1.—Properties of Sections of Rails Used in the Tests.

Rail section (full section).	Area, in square inches.	Moment of Inertia.		Section Modulus.		
		For horizontal axis.	For vertical axis.	Horizontal axis.		Vertical axis.
				Base.	Head.	Base.
85-lb. Am. Soc. C. E	8.3	30.1	....	12.2	11.1	....
90-lb. A. R. A.-A. / 90-lb. S. F.	8.8	38.7	7.5	15.2	12.6	2.9
92-lb. frictionless	9.0	32.0	8.3	14.7	10.1	3.1
101-lb. D. L. & W	9.9	38.9	9.5	15.8	13.1	3.5
105-lb. D. L. & W	10.2	50.2	9.5	18.0	15.7	3.5

3.—*The Track.*—The tests on the Atchison, Topeka and Santa Fe Railway, made in September and October, 1920, were conducted on a section of single track of the 10° curve at the west approach to the bridge over the Mississippi River, at Fort Madison, Iowa, and on the east-bound tangent track in Illinois about 2 miles east of this point; also on tangent track and curves (single track) near Ribera, N. Mex., about 27 miles west of Las Vegas. The location, weight of rail and its date of laying, tie-spacing, depth of ballast, grade, gauge, super-elevation of outer rail, and corresponding speed are given in Table 2. The ties were 6 by 8 in. by 8 ft., mostly oak in the test track in New Mexico and Iowa, and pine in Illinois. Tie-plates were in use on all ties. No curve braces were in use. The ballast in the track in New Mexico was rock

and that in Iowa and Illinois was gravel. The test section of the 10° curve at Ribera was on a fill of 12 to 14 ft.; the 10° curve at Fort Madison was on 25-ft. fill. The 6° curve at Ribera was in a shallow cut and the tangent on ground nearly at grade. The tangent in Illinois was on 6-ft. fill. The rails were laid with alternate joints. The track was used as it was found. The 10° curve at Fort Madison had recently been re-surfaced and re-aligned and was in excellent condition. The other track had not been tamped recently, but it was in fair surface and alignment.

TABLE 2.—Data of the Track.

Tie-spacing, depth of ballast, and super-elevation are given in inches, and gauge, in feet and inches.

Track.	Location.	Rail section.	Date of laying.	Tie-spacing.	Depth of ballast.	Grade, percentage.	Gauge.	Super-elevation of outer rail.	Speed of super-elevation, in miles per hour.
Tangent.....	Ribera, N. Mex........	90-lb. S. F....	1917	18	12	—1.40	4-8½	......	......
6° curve.....	" "	"	1917	18	10	—1.18	4-8⅞	4.7	35
10° curve....	" "	"	1920	19	10	—1.02	4-8⅞	4.7	27
Tangent.....	East Fort Madison, Ill.	85-lb. Am. Soc. C. E.	1906	20	22	0.0	4-8⅝	......	......
10° curve....	Fort Madison, Iowa...	90 lb. S. F....	1920	21	14	0.0	4-9⅛	2.0	17
Tangent.....	Dover, N. J...........	105-lb. D. L. & W.........	1915	22	12	—0.55	4-8¾	......	......
4° curve.....	Dover, N. J..........	105-lb. D. L. & W.........	1919	22	18	—0.63	4-8⅞	3.7	37
6° curve.....	Mt. Tabor, N. J......	{ 92-lb. Frictionless.......... / 101-lb. D. L. & W......... }	1914 / 1915	22	6	—0.84	4-8¾	8.5	46
7½ curve....	Paterson, N. J.........	105-lb. D. L. & W.........	1919	20	9	0.0	4-9	6.4	36
10° curve....	Bealville, Calif........	90-lb. A. R. A.-A	1921	22	5 on old grade	2.00	4-8⅞	4.4	26
10° curve....	Cajon, Calif...........	90-lb. S. F.....	1920	18	10	1.80	4-8½	5.4	29
7° curve.....	Murphysboro, Ill......	90-lb. A. R. A.-A	1914 / 1919	20	12	0.0	4-9⅛	3.7	28
14° curve ...	Champaign, Ill........	85-lb............	1903	19	Cinder	0.0	4-8⅞	3.8	20

The tests on the Delaware, Lackawanna and Western Railroad, made in July and August, 1920, were conducted on east-bound tangent track at Dover, N. J., on east-bound 4° curve east of Dover, on east-bound 6° curve east of Mount Tabor, N. J., and on east-bound 7½° curve at Paterson, N. J. Information about the track is given in Table 2. The ties were 7 by 9 in. by 8 ft. 6 in.; creosoted oak ties, creosoted oak and pine ties, and creosoted pine ties, respectively, were used on the three test sections. Tie-plates were used throughout and screw spikes were in use; the 7½° curve also had some driven spikes. The ballast was rock, rock on cinder, rock on gravel, and rock on sand. The tangent was a light fill, the 4° curve nearly at grade, the 6° curve on 10-ft. fill, and the 7½° curve in 5-ft. cut. The rails were laid with alternate joints. The track was tested as found and was in good surface and alignment.

The tests on the Illinois Central Railroad, made in June and July, 1920, were conducted on a 7° curve at Murphysboro, Ill., and on a 14° curve at Cham-

paign, Ill. The track was tested as found; the surface and alignment were in fairly good condition. The 7° curve had rock screenings for ballast. The 14° curve had cinder ballast. The gauge of the 7° curve was 4 ft. 9⅛ in., and that of the 14° curve, 4 ft. 8⅞ in. Tie-plates were in use.

The track at Bealville and Cajon, Calif., used in tests in 1922, is described in the discussion of the tests at these two locations.

From Table 2 it is seen that there are some differences in the gauge of the track. For example, on straight track the gauge on the test section of the Atchison, Topeka and Santa Fe Railway, at Ribera, was 4 ft. 8½ in., at East Fort Madison, it was 4 ft. 8⅝ in., and on the Delaware, Lackawanna and Western Railroad, at Dover, 4 ft. 8¾ in. The gauge of the 6° curve of the Delaware, Lackawanna and Western Railroad, at Mount Tabor, was 4 ft. 8¾ in., and that of the Atchison, Topeka and Santa Fe Railway, at Ribera, 4 ft. 8⅞ in. The gauge of the 10° curve at Fort Madison was 4 ft. 9⅛ in., at Bealville, 4 ft. 8⅞ in., and the track at Cajon was spiked to standard gauge of 4 ft. 8½ in., at the time of the test. The foregoing values were obtained by averaging several measurements. A variation of as much as ¼ in. may be found in a distance of 5 or 10 ft. It is to be expected that the gauge will widen with use after re-aligument, although measurements at given points showed no change after 4 or 5 days of testing.

The recommendation of the American Railway Engineering Association, as given in the "Manual", is to use standard gauge (4 ft. 8½ in.) for straight track and for curves up to and including 8°. It is also recommended that the gauge be widened ⅛ in. for each 2° or fraction thereof over 8° to a maximum of 4 ft. 9¼ in. It is stated that under ordinary conditions it is not necessary to re-gauge track if the increase in gauge has not amounted to more than ½ in., providing such increase is uniform, but the gauge, including widening due to wear, should never exceed 4 ft. 9½ in. The foregoing recommendation would make the gauge of a 10° curve 4 ft. 8⅝ in., with an allowable increase of ½ in. before re-alignment.

4.—The Locomotives.—Figs. 1 and 2 show the diagrams of the locomotives used on the tests of track on the Atchison, Topeka and Santa Fe Railway in New Mexico, Iowa, and Illinois, and Fig. 3, those used on track of the Delaware, Lackawanna and Western Railroad in New Jersey; wheel loads and spacings, diameter of drivers, crank-pin radius, and the number and type of the locomotive are noted. Fig. 4 shows a diagrammatic representation of the equalizing system of six of the locomotives. Tables 3 to 7, inclusive, give data of the counterbalancing of the drivers of the locomotives of the Atchison, Topeka and Santa Fe Railway, as furnished by the Mechanical Department of that Company, and Tables 8 and 9 give similar data furnished by the Delaware, Lackawanna and Western Railroad. The footnotes to these tables give the approximate modification in the counterbalance obtained by the method outlined in the second progress report for finding the effect of the outside rotating parts not being in the plane traversed by the counterweights.

The locomotives were used as they were found in service; all were in ordinary working order. Contours of the tires of the driving wheels were

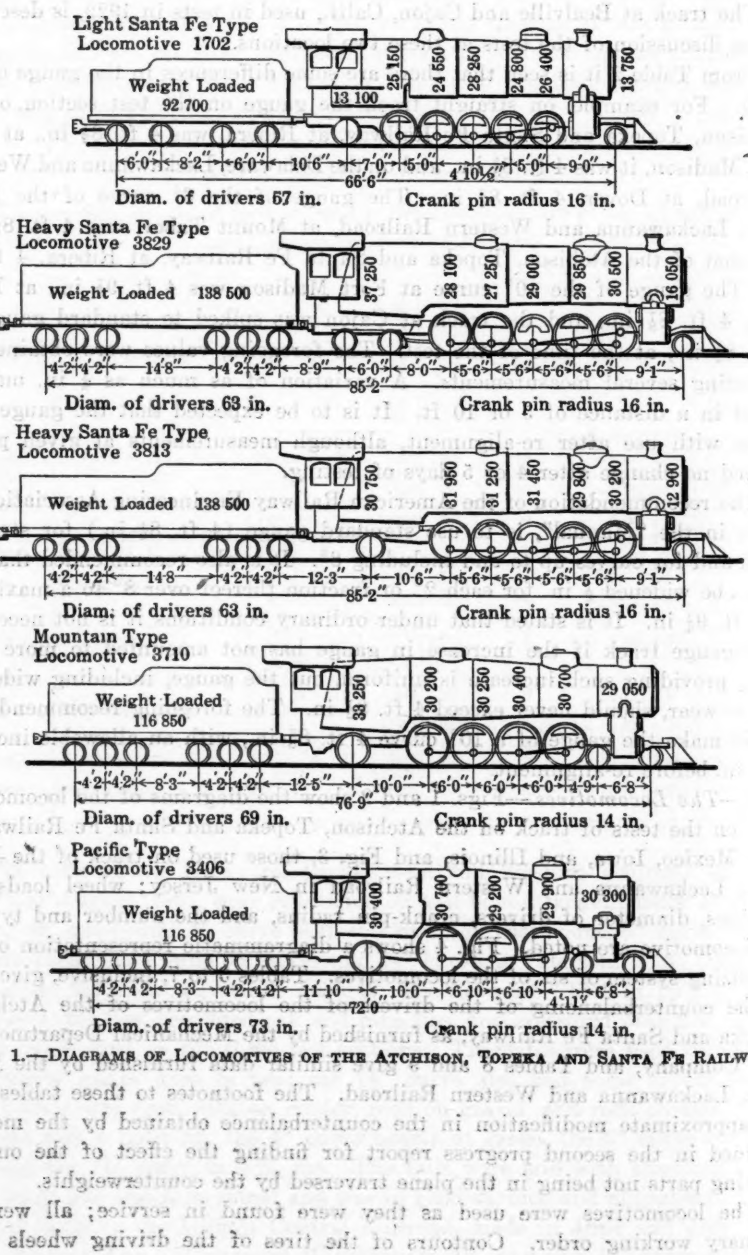

FIG. 1.—DIAGRAMS OF LOCOMOTIVES OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

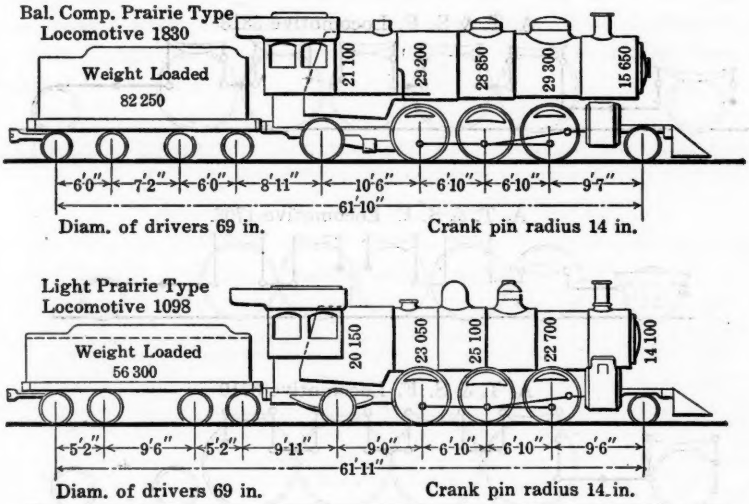

FIG. 2.—DIAGRAMS OF LOCOMOTIVES OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

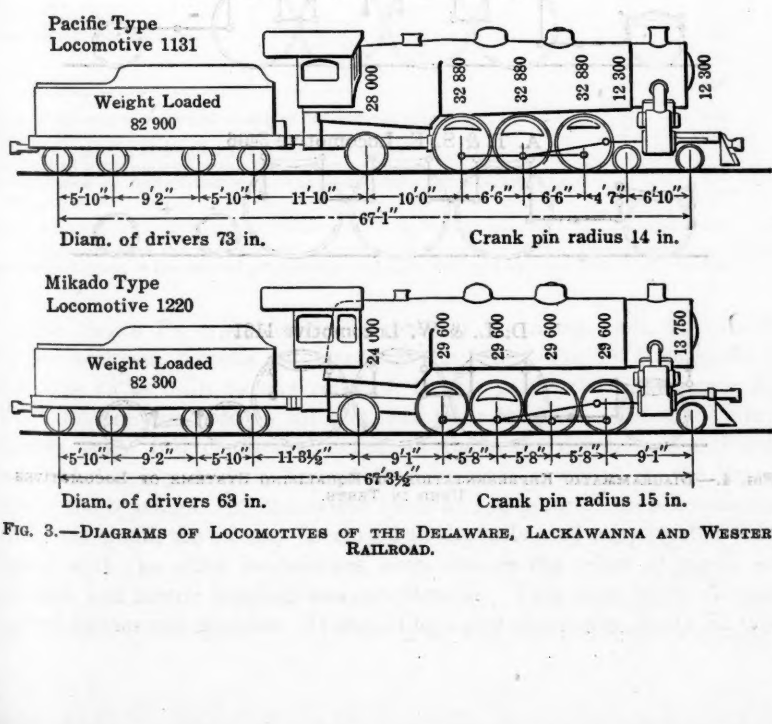

FIG. 3.—DIAGRAMS OF LOCOMOTIVES OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

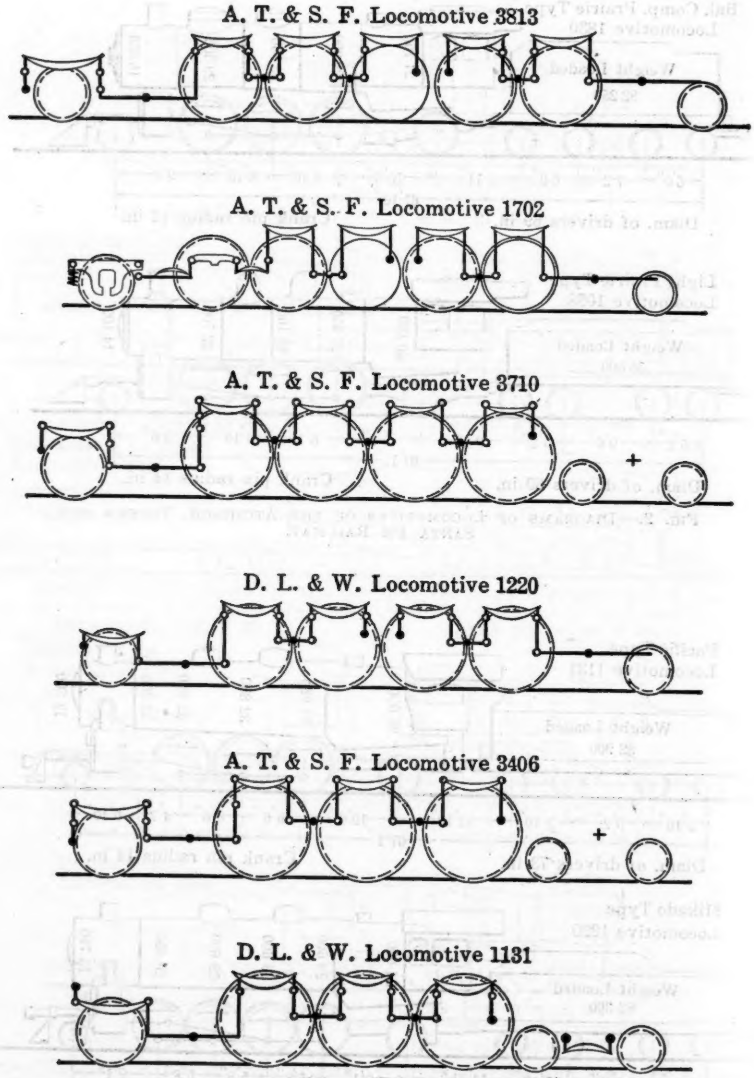

FIG. 4.—DIAGRAMMATIC REPRESENTATION OF EQUALIZING SYSTEMS OF LOCOMOTIVES USED IN TESTS.

taken; the tires may be said to have been in average condition—neither newly turned nor badly worn. No measurement of the lateral play of the driving axles in their boxes was made. The practice of the Atchison, Topeka and Santa Fe Railway is to provide a total lateral play of $\frac{1}{8}$ to $\frac{3}{16}$ in. at the boxes of the drivers when the locomotive leaves the shop. The regulations of the Interstate Commerce Commission provide that this lateral play shall not be permitted to exceed $\frac{3}{4}$ in.

TABLE 3.—Weights of Rotating and Reciprocating Parts, in Pounds, Pacific Type Locomotive of the Atchison, Topeka and Santa Fe Railway.

Reciprocating Parts.

Piston	706
Cross-head	606
Union link and lower end of combination lever	60
40% main rod, weight on cross-head pin	433
	1 805

$$\frac{0.50 \times 1\,805}{3} = 301$$

Rotating Parts.

Driver number.	3	Main.	1
50% of weight of reciprocating parts	301	301	301
Main rod, weight on crank-pin	....	650	....
Side rod, weight on crank-pin	190	705	190
Crank-pin	117	367	117
Crank-pin hub	89	153	89
One-half of eccentric crank	....	82	....
Total	697	2 258	697
Equivalent weight required at center of counterweight	372	1 435	372
Weight used	372	1 435	372
Difference in weight required and weight obtained	0	0	0
Equivalent difference at crank-pin center	0	0	0
Overbalance or underbalance at crank-pin circle for rotating parts only	+301	+301*	+301

* If the effect of the rods and pin not being in the plane of the counterweight is calculated by the method given in the second progress report, this becomes approximately an overbalance of 35 lb.

The Santa Fe type locomotive received the name from its introduction by the Atchison, Topeka and Santa Fe Railway. The 1674 class, the first of this type to be built by any railroad, is here called the light Santa Fe type. No. 1702, the one used in the test, was built in 1903. The small size of the drivers made full counterbalancing on the main driver impracticable, and counterbalancing devices, known as bobs, were attached to the driver axle inside the bearings. As the driver loads and spacing of these locomotives are relatively small, the stresses developed in the rails used were smaller than those found with the other locomotives, even though the effect of speed, counterbalance, and lateral bending was considerable. They were built, of course, for use on lighter rail sections. It should be noted that many Santa Fe type loco-

motives with 57-in. drivers still remain in use on a number of railroads of the United States, and some of these locomotives are not of as good design as the 1674 class locomotives. The Heavy Santa Fe type locomotive was not only much heavier, but the design was greatly improved, and its general performance on the track was much better than the lighter locomotive; No. 3813, the one used, had been in service about a year, as had the Mountain type and the Pacific type of the Atchison, Topeka and Santa Fe Railway. Locomotives of the Prairie type used had been in service from 15 to 20 years. The only change made in the locomotives during the tests was in the Mountain type; the lateral spring holding the trailer was removed for the last part of the tests. The Double Trailer Heavy Santa Fe type is the term given to the one locomotive which the railroad had equipped with four trailing wheels for experimental purposes; this is the only locomotive to which the double trailer had been applied.

TABLE 4.—WEIGHTS OF ROTATING AND RECIPROCATING PARTS, IN POUNDS, LIGHT PRAIRIE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

RECIPROCATING PARTS.

Piston	752
Cross-head	392
Weight of main rod on cross-head pin	297
	1 441

$$\frac{0.666 \times 1\ 441}{3} = 320$$

ROTATING PARTS.

Driver number.	3	Main.	1
Two-thirds of weight of reciprocating parts	320	320	320
Main rod, weight on crank-pin	...	297	...
Side rod, weight on crank-pin	163	1 100	170
Crank-pin	100	280	100
Crank-pin hub	90	160	90
Total	673	2 157	680
Equivalent weight required at center of counterweight	410	1 630	414
Weight used	410	1 630	414
Difference between weight required and weight obtained	0	0	0
Equivalent difference at crank-pin circle	0	0	0
Overbalance or underbalance at crank-pin circle for rotating parts only	+320	+320	+320

The Mikado type locomotive of the Delaware, Lackawanna and Western Railroad was built in 1913 and the Pacific type used was built in 1915. These two types of locomotives were also used in the tests made on this railroad in 1916.

In the tests made in California, the locomotive of the Atchison, Topeka and Santa Fe Railway used was the same as the Heavy Santa Fe type shown in Fig. 1, except that on account of the use of oil burners the weight on the

trailer was only 22 900 lb. That of the Southern Pacific Company had nearly the same driver loads, but the load on the trailer was 29 400 lb. The Mikado type locomotive used in the preliminary tests on the Illinois Central Railroad was of the same class as that used on that railroad in 1918. The Ten-Wheel type was a much lighter locomotive.

TABLE 5.—WEIGHTS OF ROTATING AND RECIPROCATING PARTS, IN POUNDS, MOUNTAIN TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

RECIPROCATING PARTS.

Piston	904
Cross-head	610
Union link and lower end of combination lever	62
40% main rod, weight on cross-head pin	522
	2 098

$$\frac{0.50 \times 2\ 098}{4} = 262$$

ROTATING PARTS.

Driver number.	4	3	Main.	1
50% of weight of reciprocating parts	262	262	262	262
Main rod, weight on crank-pin	....	....	783	....
Side rod, weight on crank-pin	180	530	665	175
Crank-pin	135	130	430	100
Crank-pin hub	129	129	266	129
One-half eccentric crank	....	....	87	....
Total	706	1 051	2 493	666
Equivalent weight required at center of counterweight	417	640	1 939	417
Weight used	417	640	1 939	417
Difference between weight required and weight obtained	0	0	0	0
Equivalent difference at crank-pin circle	0	0	0	0
Overbalance or underbalance at crank-pin circle for rotating parts only	+262	+262	+262*	+262

*If the effect of the rods and pin not being in the plane of the counterweight is calculated by the method given in the second progress report, this becomes approximately an underbalance of 35 lb.

5.—*The Conduct of the Tests and the Reduction of the Data.*—The methods used in the tests of track were the same as those used in the tests described in the first and second progress reports. Eight stremmatographs were used simultaneously. (A description of these instruments will be found in the first progress report*). Four stremmatographs were placed on one rail between ties at distances apart approximately equal to the average spacing of the drivers of the locomotive used on the test, and the other four instruments directly opposite on the other rail. The driving mechanism used rotated the disks of all the instruments simultaneously. The correlation of a point on the record of one of the disks with the point of any other disk at the same moment was possible. As the locomotive passed the test section a record of the strains in the rail was made on each instrument. The passage of each wheel of one side

* *Transactions*, Am. Soc. C. E., Vol. LXXXII (1918), p. 1224.

of the locomotive and tender thus was recorded on four instruments and each wheel of the other side on four other instruments. A run then gave records of what happened under one pair of wheels on eight instruments, and as each instrument holds two disks, sixteen records in all were made. As usually operated, a disk would hold the records of four runs. Fresh disks would then be inserted.

TABLE 6.—WEIGHTS OF ROTATING AND RECIPROCATING PARTS, IN POUNDS, LIGHT SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

RECIPROCATING PARTS.

Piston	985
Cross-head	480
Union link and lower end of combination lever	65
48% main rod, weight on cross-head pin	470
	2 000

$$\frac{0.666 \times 2\,000}{5} = 267$$

ROTATING PARTS.

Driver number.	5	4	Main.	2	1
Two-thirds of weight of reciprocating parts	267	267	267	267	267
Main rod, weight on crank-pin	....	....	510	....	....
Side rod, weight on crank-pin	125	302	762	314	125
Crank-pin	70	70	390	70	67
Crank-pin hub	157	157	325	157	157
Total	619	796	2 254	808	616
Equivalent weight required at center of counterweight	604	836	2 365	848	602
Weight used	588	760	1 495	802	579
Difference between weight required and weight obtained	−16	−76	−870	−46	−23
Equivalent difference at crank-pin circle	−17	−72	−828	−44	−23
Overbalance or underbalance at crank-pin circle for rotating parts only	+250	+195	−561*	+223	+244

* No information is at hand on the weight or position of the bobs or position of planes of the outside rotating parts.

The use of eight stremmatographs—four had been the largest number used in previous tests—had advantages even on the tests of straight track. The strain under companion drivers was recorded simultaneously; in fact, with just the right spacing, the strain under four pairs of wheels was recorded at the same instant, thus giving the instantaneous effect of the four pairs of drivers. The distance from the first instrument to the fourth was generally about equal to the circumference of a driver; this facilitated finding the effect of counterbalance. The use of eight instruments was more likely to give the general effect of the locomotive as a whole, at a given time, than the smaller number. The time taken to obtain an adequate number of data was shortened, thus reducing the time the locomotive was taken from service.

The chief purpose in using eight instruments, however, was to facilitate the tests on curved track, where, of course, the stresses in the two rails are

generally unequal. The use of two disks in each stremmatograph, one recording the strain at one edge of the base of rail and the other that at the other edge, permitted the measurement of the lateral bending strains in the rails of curved track. It is believed that these measurements of the bending stresses developed in curved track were the first to be made in any tests. The means used were entirely successful. The preliminary tests made to learn the precautions and methods necessary for the satisfactory conduct in the testing of curved track were made on a curve of a branch line. It will be noted that by the method used the stresses in the two edges of both inner and outer rail of the curved track, caused by both the vertical bending and the lateral bending of the rail, were measured under four pairs of drivers at about the same time.

TABLE 7.—WEIGHTS OF ROTATING AND RECIPROCATING PARTS, IN POUNDS, HEAVY SANTA FE TYPE LOCOMOTIVES OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

RECIPROCATING PARTS.

Piston	1 070
Cross-head	705
Union link and lower end of combination lever	62
40% main rod, weight on cross-head pin	585
	2 422

$$\frac{0.50 \times 2\,422}{4} = 303^*$$

ROTATING PARTS.

Driver number.	5	4	Main.	2	1
50% of weight of reciprocating parts	308	308	....	308	808
Main rod, weight on crank-pin	....	....	877	....	....
Side rod, weight on crank-pin	172	493	785	454	166
Crank-pin	118	130	500	130	105
Crank-pin hub	144	144	271	144	144
One-half eccentric crank	....	....	91	....	....
Total	742	1 075	2 524	1 036	723
Equivalent weight required at center of counterweight	574	899	2 714	866	564
Weight used	574	899	2 693	866	564
Difference between weight required and weight obtained	0	0	21	0	0
Equivalent difference at crank-pin circle	0	0	20	0	0
Overbalance or underbalance at crank-pin circle for rotating parts only	+308	+308	−20†	+308	+308

* It was not possible to counterbalance for the whole of the rotating weight in the main wheel; the deficiency of 21 lb. was distributed equally among the other drivers, bringing their total up to 308 lb.

† If the effect of the rods and pin not being in the plane of the counterweight is calculated by the method given in the second progress report, this becomes approximately an underbalance of 360 lb.

Unless otherwise noted, in all runs steam was shut off as the locomotive approached the test section of track, and the locomotive "coasted" past the instruments. The speeds were read from a speedometer in the cab connected with the tread of the trailer or the front wheel of the tender, the instrument having been checked up over a measured length of track. The locomotive was

then backed over the track and the next run made. For each set of tests, the order of speeds for consecutive runs was the same, varying from the lowest speed to the highest.

TABLE 8.—WEIGHTS OF ROTATING AND RECIPROCATING PARTS, IN POUNDS, PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

RECIPROCATING PARTS.

Piston	961
Cross-head	585
Weight of main rod on cross-head pin	335
	1 881

$$\frac{2 \times 1\,881}{3 \times 3} = 418$$

ROTATING PARTS.

Driver number.	3	Main.	1
Two-thirds of weight of reciprocating parts	418	418	418
Main rod, weight on crank-pin	....	627	....
Side rod, weight on crank-pin	159	517	145
Crank-pin	116	398	114
Crank-pin hub	113	226	113
One-half eccentric crank	....	60	....
Total	806	2 246	790
Equivalent weight required at center of counterweight	478	1 562	468
Weight used	478	1 562	468
Difference between weight required and weight obtained	0	0	0
Equivalent difference at crank-pin circle	0	0	0
Overbalance or underbalance at crank-pin circle for rotating parts only	+418	+418*	+418

*If the effect of the rods and pin not being in the plane of the counterweight is calculated by the method given in the second progress report, this becomes approximately an overbalance of 175 lb.

The position of the counterweight with respect to one instrument was observed for each run. It was found unnecessary to control the position of counterweight on different runs; the starting and stopping and the running over curves within the length of the runs gave sufficient distribution of the position of counterweight with respect to the instruments throughout the revolution of the driver.

Fig. 5 shows the position of the stremmatographs in one of the tests of curved track. Variations from this arrangement were made, but the diagram is representative of all the tests. As all track was laid with alternate joints, it was necessary that a rail joint lie within the test section. Generally, the joint was between the two middle instruments, sometimes on one rail and sometimes on the other. A study of the records of the several instruments failed to show any general characteristics of the strains recorded in the instrument nearest the rail joint.

The process followed in the reduction of the data obtained by the stremmatographs was the same as that which was described in the earlier reports.

The stremmatograph records were read with a binocular microscope fitted with a micrometer eyepiece. Readings were taken for points in the record corresponding to a wheel over the instrument and to a point between wheels, the

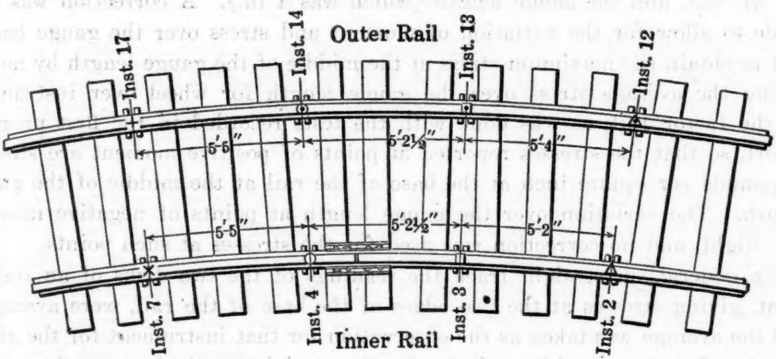

FIG. 5.—POSITION OF EIGHT STREMMATOGRAPHS IN A TEST OF CURVED TRACK.

high point of the record being assumed to have been made when the wheel was directly over the instrument. In reducing these measurements, the readings were multiplied by the proper microscopic constant and then reduced to

TABLE 9.—WEIGHTS OF ROTATING AND RECIPROCATING PARTS, IN POUNDS, MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

RECIPROCATING PARTS.

Piston	1 097
Cross head	570
Weight of main rod on cross-head pin	405
	2 072

$$\frac{2 \times 2\,072}{3 \times 4} = 345$$

ROTATING PARTS.

Driver number	4	Main.	2	1
Two-thirds of weight of reciprocating parts	345	345	345	345
Main rod, weight on crank pin	....	670	....	....
Side rod, weight on crank-pin	130	392	308	135
Crank-pin	83	406	77	67
Crank-pin hub	135	210	135	127
One-half eccentric crank	....	66	....	....
Total	693	2 089	865	674
Equivalent weight required at center of counterweight	530	2 089	661	515
Weight used	530	2 089	661	515
Difference between weight required and weight obtained	0	0	0	0
Equivalent difference at crank-pin circle	0	0	0	0
Overbalance or underbalance at crank-pin circle for rotating parts only	+345	+345*	+345	+345

*If the effect of the rods and pin not being in the plane of the counterweight is calculated by the method given in the second progress report, this becomes approximately an overbalance of 95 lb.

stresses by multiplying by a constant which involves the position of the neutral axis of the rail section, the vertical distance of the needle-bar below the base of the rail, the modulus of elasticity of steel (taken as 30 000 000 lb. per sq. in.), and the gauge length (which was 4 in.). A correction was also made to allow for the variation of moment and stress over the gauge length and to obtain the maximum stress at the middle of the gauge length by multiplying the average stress over the gauge length for wheel over instrument by the factor 1.04, as was done with the tests recorded in the first progress report, so that the stresses reported at points of positive moment are stresses in pounds per square inch at the base of the rail at the middle of the gauge length. The variation over the gauge length at points of negative moment was slight, and no correction was used for the stresses at such points.

In general, on straight track the readings of the two disks of an instrument, giving stresses at the two edges of the base of the rail, were averaged, and the average was taken as the observation for that instrument for the given run for the given position of wheel. On straight track, in case the record of one disk of an instrument was defective and that on the companion disk was clear, the one good record was usually also discarded. In the case of curved track, all readable records were used, even though the record on the companion disk was defective. It was desired to keep the strains at the two edges separated. It was also found that on curved track there was less vibration in the rail and less opportunity for errors being introduced through the use of a record at only one edge. Besides, it was found that defective records were less frequent on curved track, usually less than 10% of the points having to be discarded.

The accuracy of the records and their reduction is considered to be as good as that of the stremmatograph data reported in the two earlier reports.

The time required for the reduction of the data of the large number of observations made in all the tests was considerable. The reading of the stremmatograph records, the calculation of the data, and the representation of the results for study and interpretation involved a large amount of work, as may be judged from a consideration of the number of microscopic readings of strains made, approximately 470 000. With clear records, skilled observers learned to make 1 000 to 1 200 such readings per day.

Table 1 gives the properties of the sections of the rails new. Profiles were taken of the sections of the rail in the track. With the exception of the 105-lb. rail on the Delaware, Lackawanna and Western Railroad, the rails were not worn enough to have a sufficiently marked effect on the moment of inertia and section modulus about the horizontal axis to make it seem necessary to use the section modulus of the worn rail in the analytical calculation of stresses in rail. On the $7\frac{1}{2}°$ curve, the moment of inertia and section modulus of the inner rail were reduced about 3% and of the outer rail about 6%, but, in this case also, the properties of the new rail have been used in making comparisons. The effect of wear on the section modulus about a vertical axis would be small, as the base of rail, which is not changed, forms the large

factor in making up the section modulus. For lateral bending of the rail on curved track, the properties of new rails were also used.

II.—Tests on Straight Track

6.—Results of Tests.—The tests on straight track, although made for the purpose of supplying a basis of comparison with results on curved track, furnish considerable additional information on the action of straight track, particularly on the effect of speed and counterbalance with several types of locomotives.

To determine the stiffness of track and the value of the modulus of elasticity of rail support, u, measurements of track depression under the truck of loaded cars were made. For the significance of the term, modulus of elasticity of rail support, see the first progress report of the Committee.* The method of making the test was similar to that described in the first progress report, the level bar being used.

On the Atchison, Topeka and Santa Fe Railway, the lighter of the two loads applied was an empty car, and the heavier load was a heavily loaded coal car. On the Delaware, Lackawanna and Western Railroad, the lightest load was an empty car, the medium load a loaded coal car, and the heaviest load a coal car heavily loaded with ore. In each case, the load considered was that on one truck at an end of the car. The load on the wheels of the truck used was carefully weighed, a check on the weight being obtained by also weighing the load on the other truck and the load on the whole car.

Figs. 6 and 7 give the results of tests of track depression on the Atchison, Topeka and Santa Fe Railway, at Ribera, N. Mex., and Figs. 8 and 9, the results of tests on the track of the Delaware, Lackawanna and Western Railroad, at Dover, N. J. Location A on the Atchison, Topeka and Santa Fe Railway covered the location of the stremmatographs on the regular tests at Ribera; Location B was 130 ft. east of Location A. Location C coincided with the location of the stremmatographs at Dover; and Location D was 260 ft. east of Location C. The track depression profiles indicate that the track on which the tests were made was in fairly good condition, the "play curve" showing uniformity of play between rail and tie and tie and ballast, and uniformity of stiffness in each case.

The value of the modulus of elasticity of rail support, u, calculated from these track depression profiles by the method described in the first progress report, was 1 600 lb. per lin. in. of rail, for the track on both the Atchison, Topeka and Santa Fe Railway and the Delaware, Lackawanna and Western Railroad. These values indicate a fairly stiff track.

In all the tests to find the stresses in the rail, four stremmatographs were placed on one rail and four on the other, the four instruments on one rail being spaced at distances of about 66 in., and the set on the other rail being placed directly opposite. For all stress diagrams on straight track, the stress given is the mean stress in base of rail, that is, the average of the stresses

* *Transactions*, Am. Soc. C. E., Vol. LXXXII (1918), p. 1204; *Proceedings*, Am. Ry. Eng. Assoc., Vol. 19, p. 884.

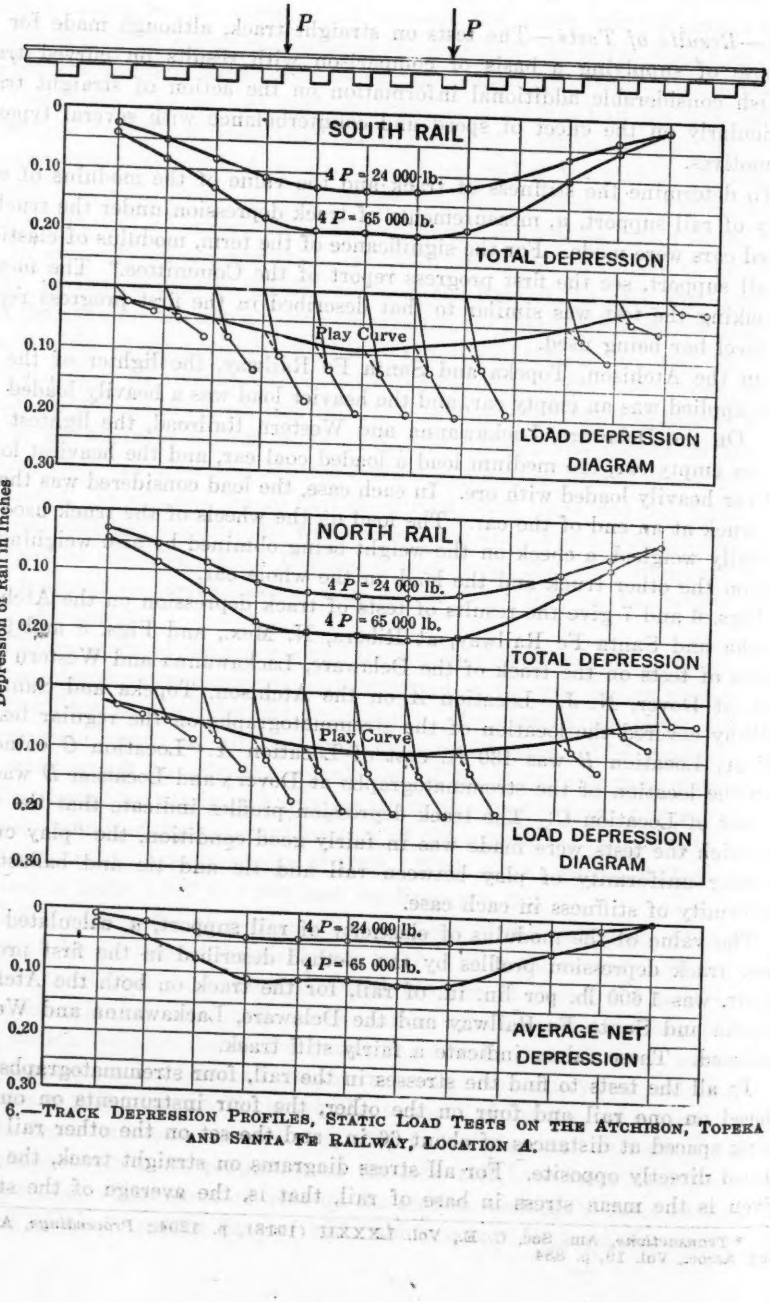

FIG. 6.—TRACK DEPRESSION PROFILES, STATIC LOAD TESTS ON THE ATCHISON, TOPEKA AND SANTA FE RAILWAY, LOCATION A.

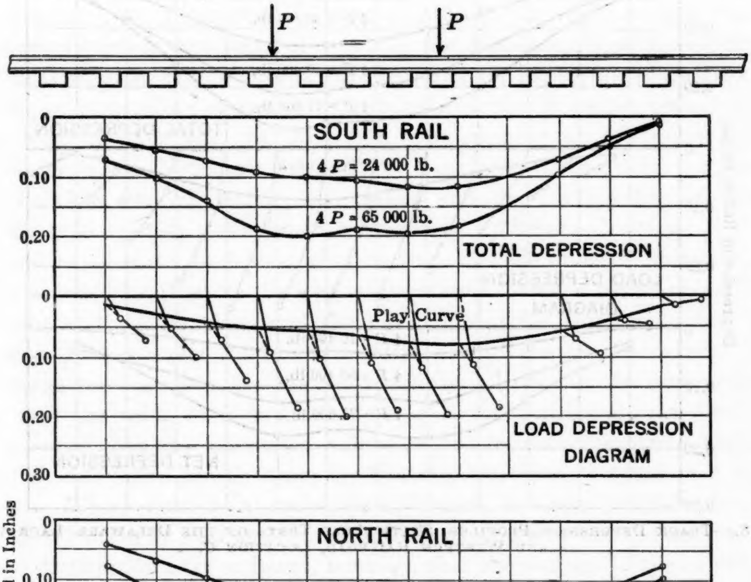

FIG. 7.—TRACK DEPRESSION PROFILES, STATIC LOAD TESTS ON THE ATCHISON, TOPEKA AND SANTA FE RAILWAY, LOCATION *B*.

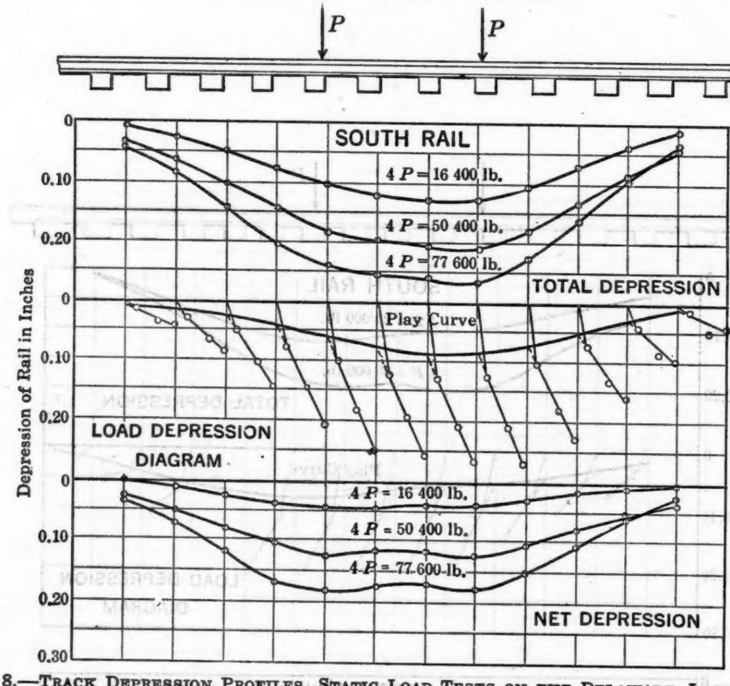

FIG. 8.—TRACK DEPRESSION PROFILES, STATIC LOAD TESTS ON THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD, LOCATION *C*.

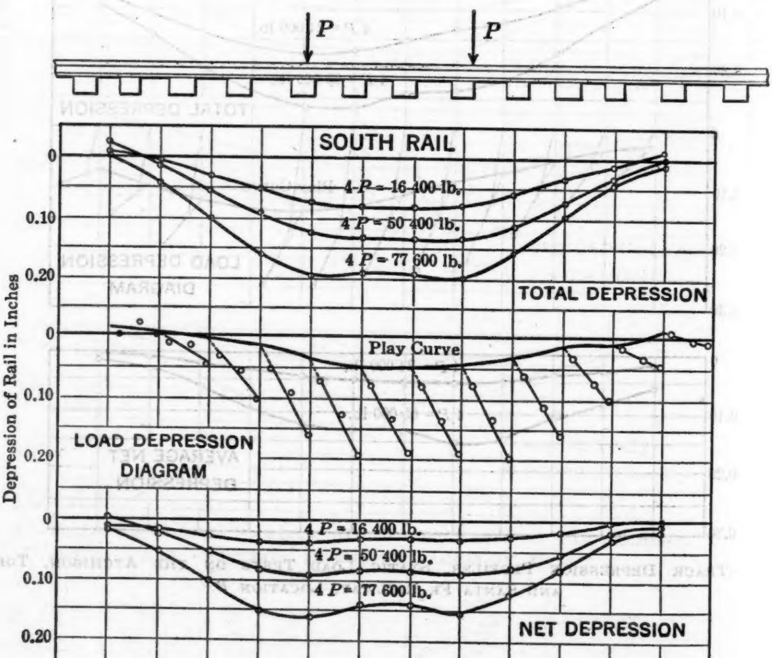

FIG. 9.—TRACK DEPRESSION PROFILES, STATIC LOAD TESTS ON THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD, LOCATION *D*.

at the outside and inside edges of the rail, and the stress there recorded is the average of the results on both rails as found from the records of the eight instruments. In Figs. 10, 11, and 12 are given the mean stress in the base of rail for the high and the low position of the counterweight for the Pacific type locomotive, the Light Prairie type, and the Balanced Compound Prairie type, respectively, in the tests of track of the Atchison, Topeka and Santa Fe Railway at East Fort Madison, Ill. In Figs. 13, 14, 15, 16, 17, and 20 are given the corresponding stresses for the tests with the Mountain type locomotive coasting down grade, the Mountain type running up grade, the Light Santa Fe type and the Heavy Santa Fe type coasting down grade, the Heavy Santa Fe type working steam down grade and the Double Trailer Heavy Santa Fe type coasting down grade, respectively, at Ribera, N. Mex.

In Tables 10 to 18, inclusive, are given the average or mean values of the stresses in base of rail under the locomotive wheels found in the tests, and also the values at the high point and the low point of the counterweight. The calculated stresses under the nominal static wheel loads are also given. The calculations are based on the method of analysis given in the first progress report, and the value of u from the tests of track depression was used. It will be noted that the calculated values of the stresses for static loads in general do not differ greatly from the observed values at a speed of 5 miles per hour. Where there is a noticeable difference, it seems probable that the actual distribution of load among the individual wheels is not the same as the assumed distribution. It is found, however, that the average of the calculated stress under the several wheels of the locomotive is almost exactly the same as the average of the observed stresses under the wheels at a speed of 5 miles per hour, the greatest difference in all the tests being about 6 per cent.

TABLE 10.—Stresses in Rail with Pacific Type Locomotive of the Atchison, Topeka and Santa Fe Railway. Maximum, Minimum, and Mean Values from Curves for Series 5450-5458.

Stresses are given in pounds per square inch at base of rail.

Speed, in miles per hour.	Position of counterweight.	Trailer.	Driver Number.			Front Truck Wheels.	
			3	Main.	1	2	1
5	Mean value	20 700	18 900	17 700	17 500	6 000	10 400
25	Up	......	18 000	......	......	......	......
	Down	......	23 000	......	......	......	......
	Mean value	21 400	20 200	18 800	19 200	6 900	11 800
40	Up	......	16 500	22 000	18 500	......	......
	Down	......	26 500	15 500	23 000	......	......
	Mean value	21 800	21 000	19 100	20 500	7 700	12 800
60	Up		17 500	27 000	17 500	......	......
	Down		29 000	18 500	26 500	......	......
	Mean value	23 400	23 500	23 100	22 200	9 800	13 800
Calculated stress under static load		22 900	19 600	15 000	17 000	4 600	9 400
Calculated additional stress due to counterbalance at 60 miles per hour		......	+5 900	+4 700	+5 900	......	......

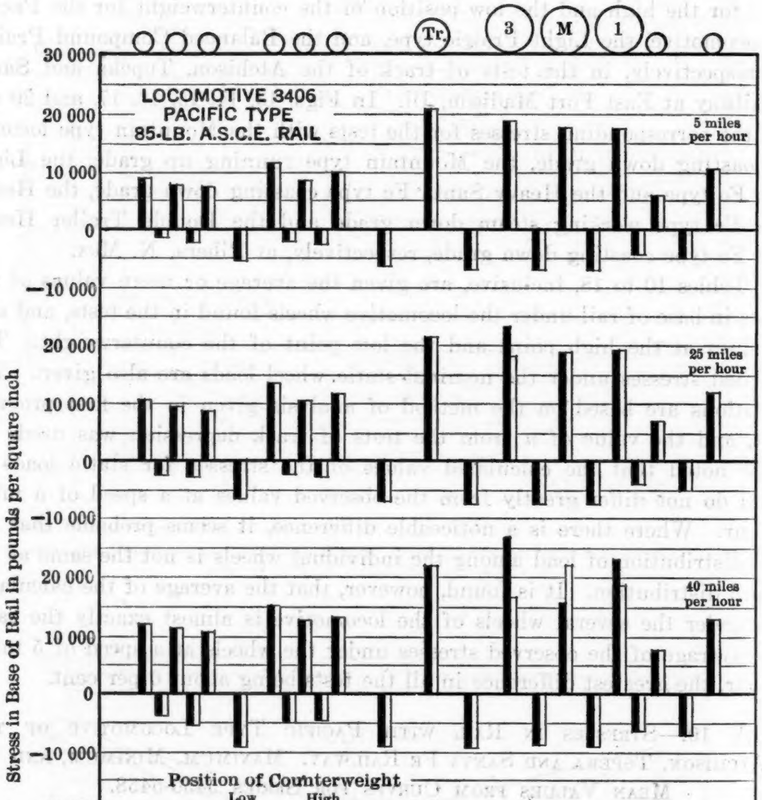

FIG. 10.—STRESS IN RAIL ON STRAIGHT TRACK AT HIGH AND LOW POSITION OF COUNTERWEIGHT, SERIES 5450–5458, PACIFIC TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

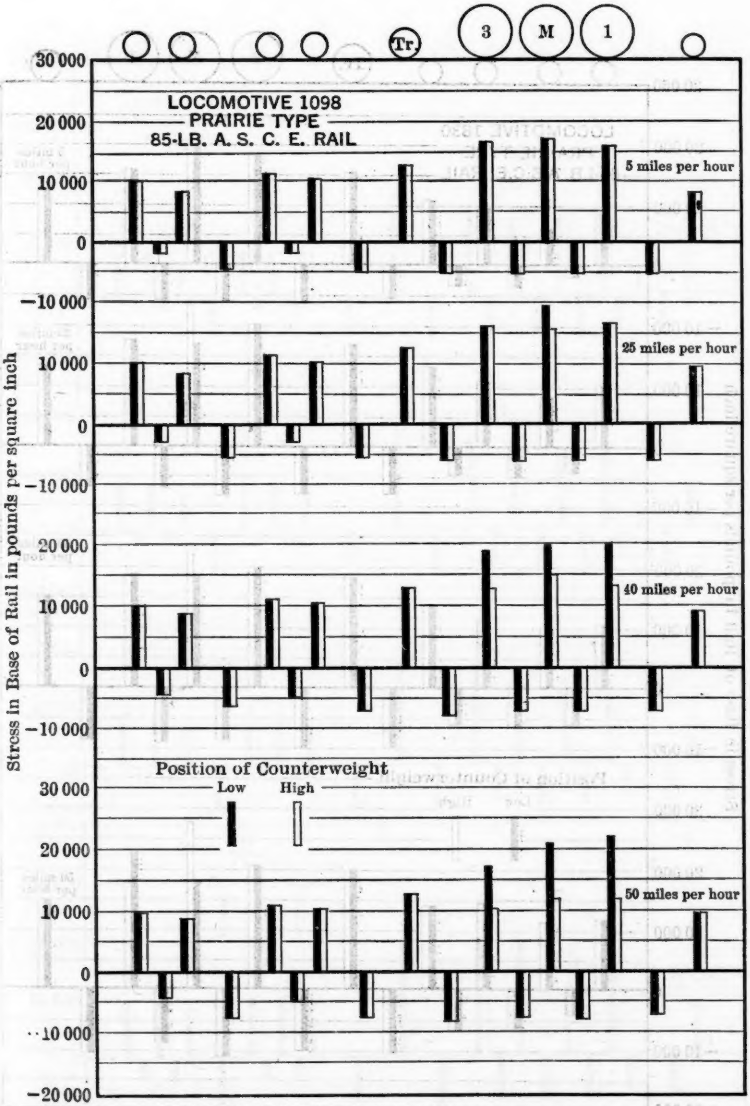

FIG. 11.—STRESS IN RAIL ON STRAIGHT TRACK AT HIGH AND LOW POSITION OF COUNTERWEIGHT, SERIES 5441–5449, LIGHT PRAIRIE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

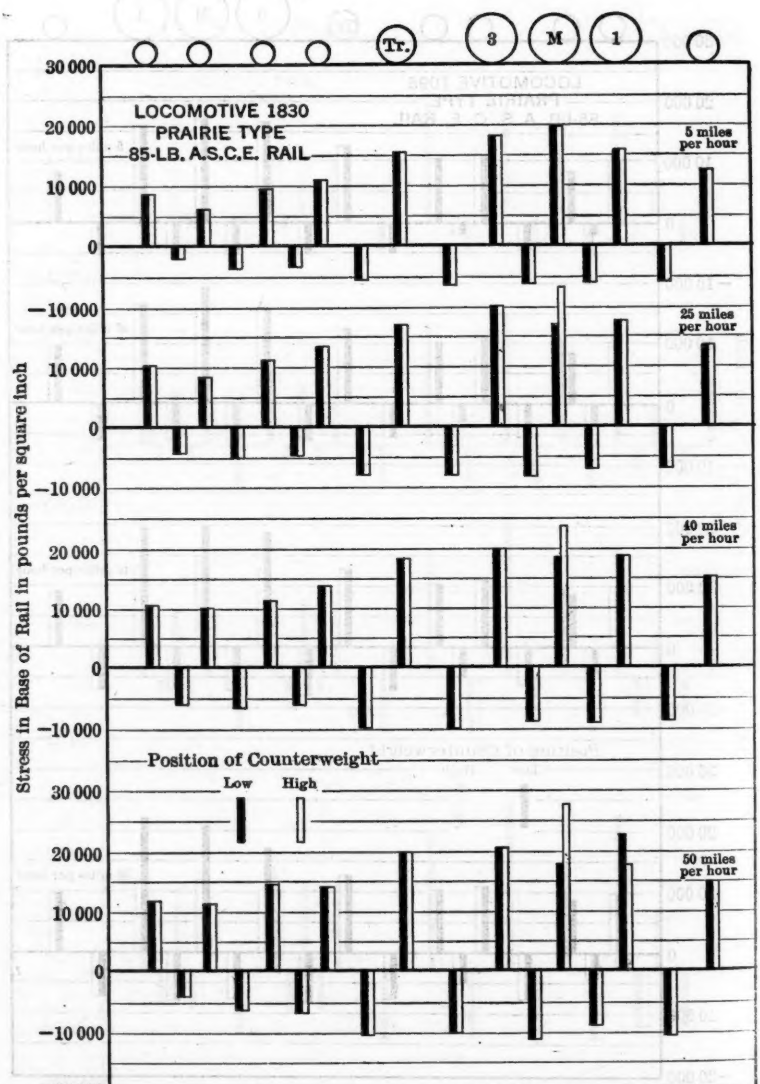

Fig. 12.—Stress in Rail on Straight Track at High and Low Position of Counterweight, Series 5434–5440, Balanced Compound Prairie Type Locomotive of the Atchison, Topeka and Santa Fe Railway.

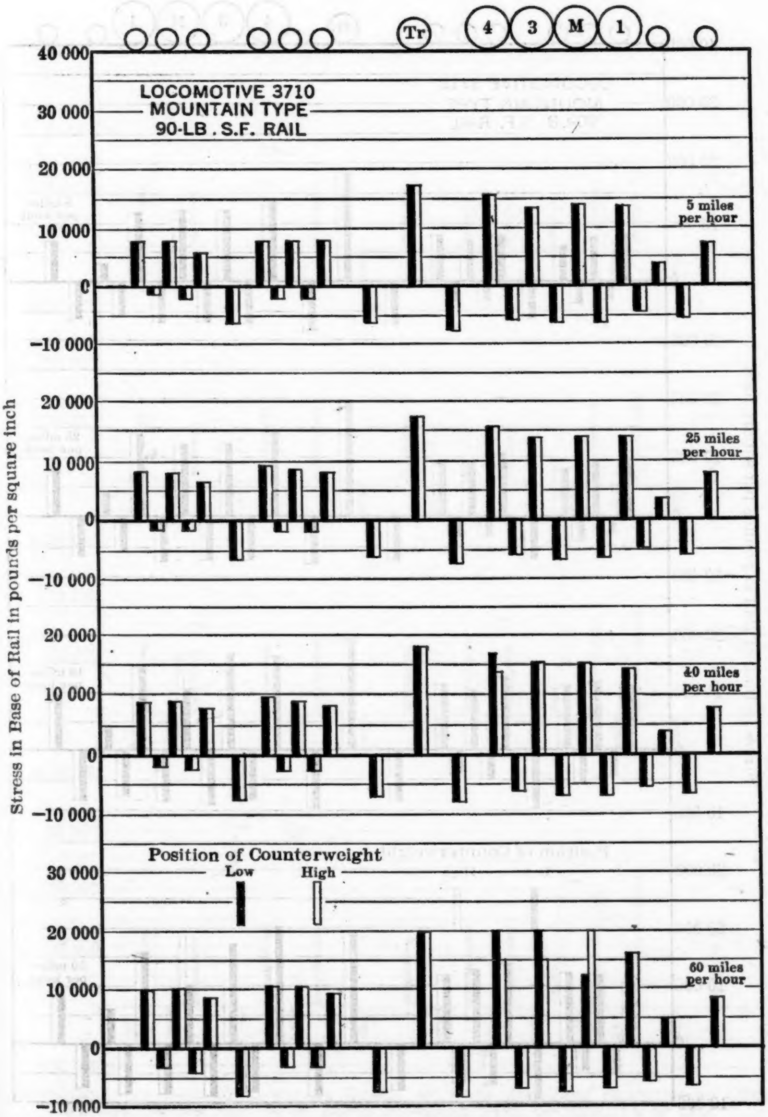

FIG. 13.—STRESS IN RAIL ON STRAIGHT TRACK AT HIGH AND LOW POSITION OF COUNTERWEIGHT, SERIES 5338–5344, MOUNTAIN TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

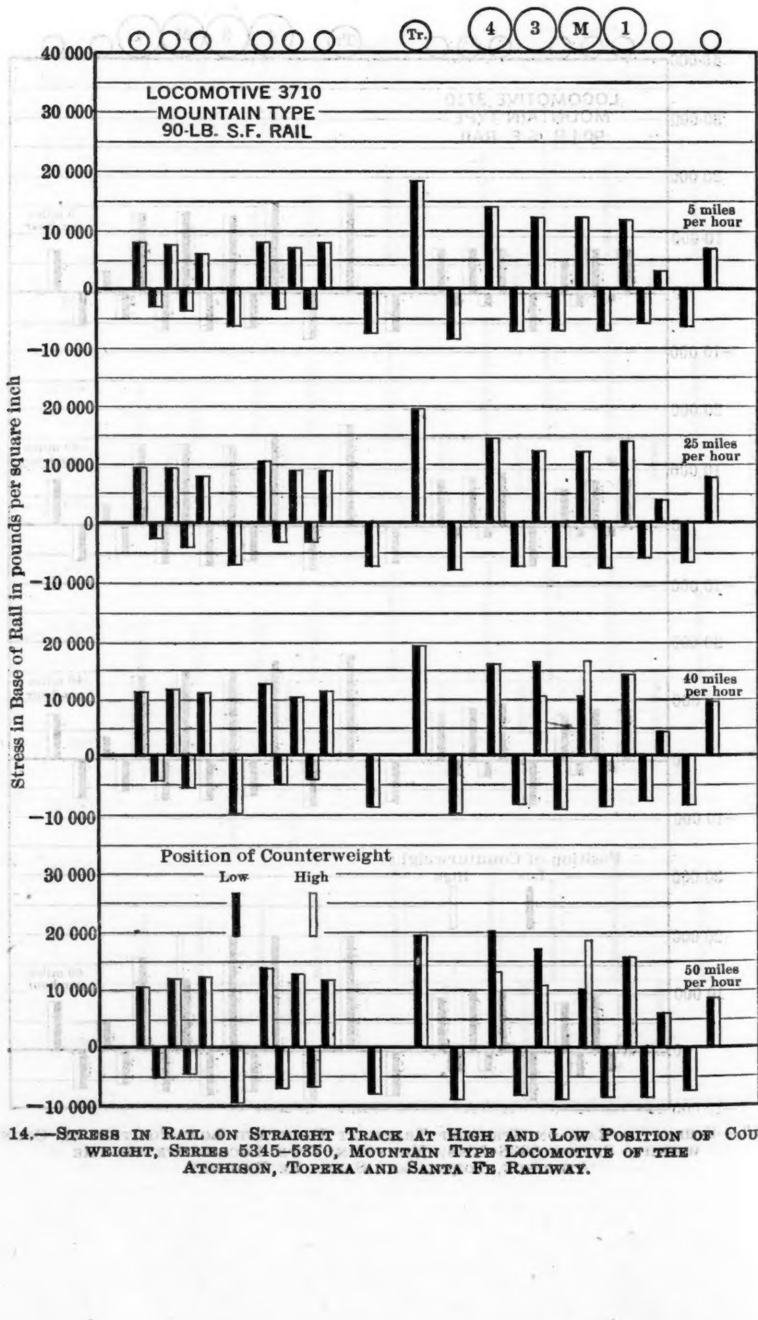

FIG. 14.—STRESS IN RAIL ON STRAIGHT TRACK AT HIGH AND LOW POSITION OF COUNTERWEIGHT, SERIES 5345–5350, MOUNTAIN TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

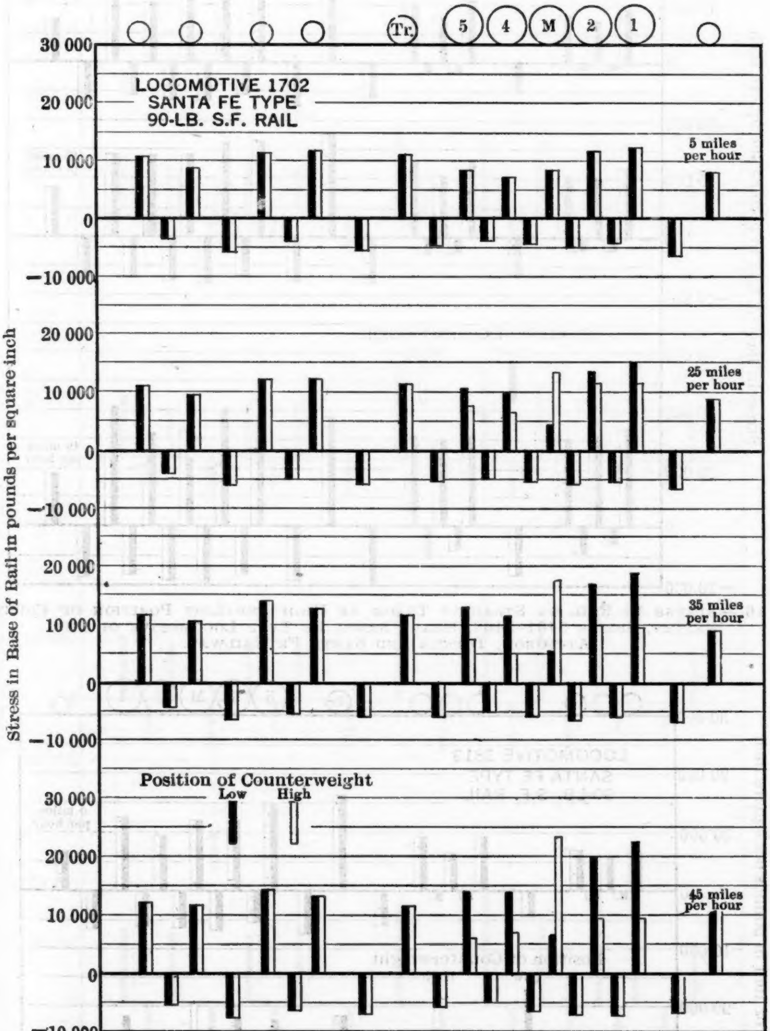

FIG. 15.—STRESS IN RAIL ON STRAIGHT TRACK AT HIGH AND LOW POSITION OF COUNTERWEIGHT, SERIES 5300–5318, LIGHT SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

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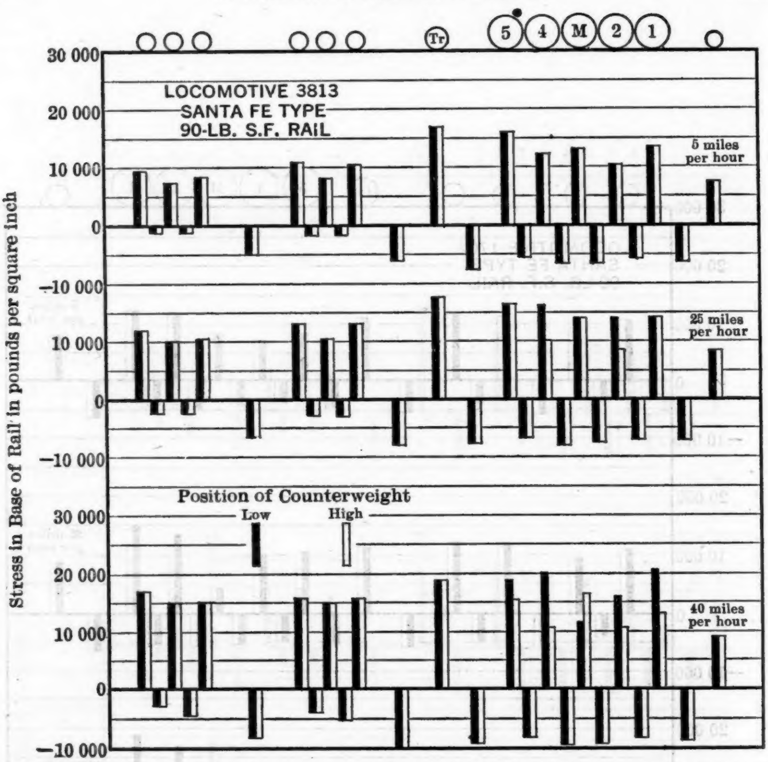


FIG. 16.—STRESS IN RAIL ON STRAIGHT TRACK AT HIGH AND LOW POSITION OF COUNTERWEIGHT, SERIES 5401–5408, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

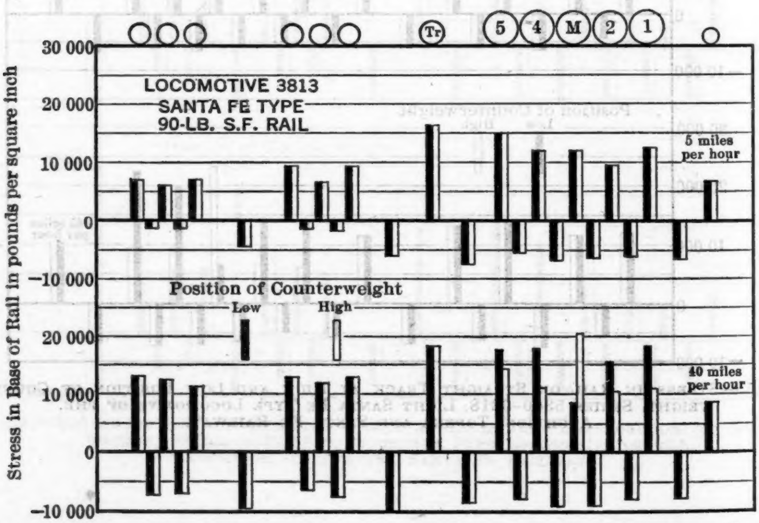


FIG. 17.—STRESS IN RAIL ON STRAIGHT TRACK AT HIGH AND LOW POSITION OF COUNTERWEIGHT, SERIES 5409–5415, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

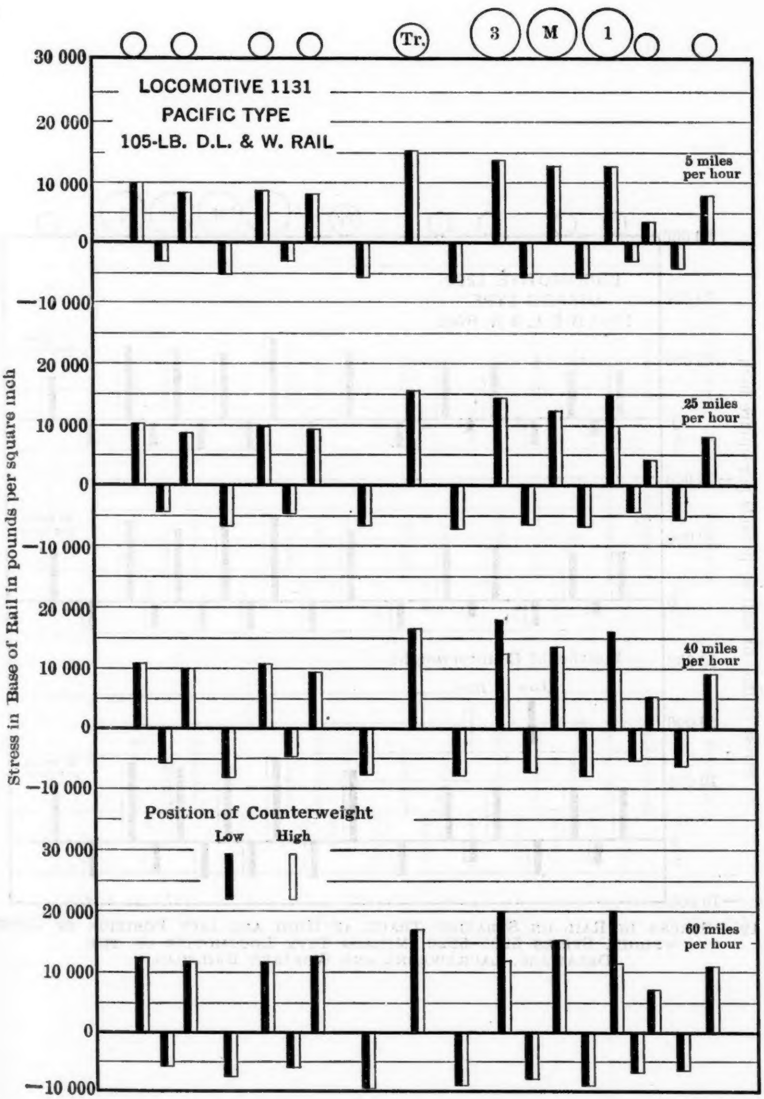


FIG. 18.—STRESS IN RAIL ON STRAIGHT TRACK AT HIGH AND LOW POSITION OF COUNTERWEIGHT, SERIES 5136–5149, PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

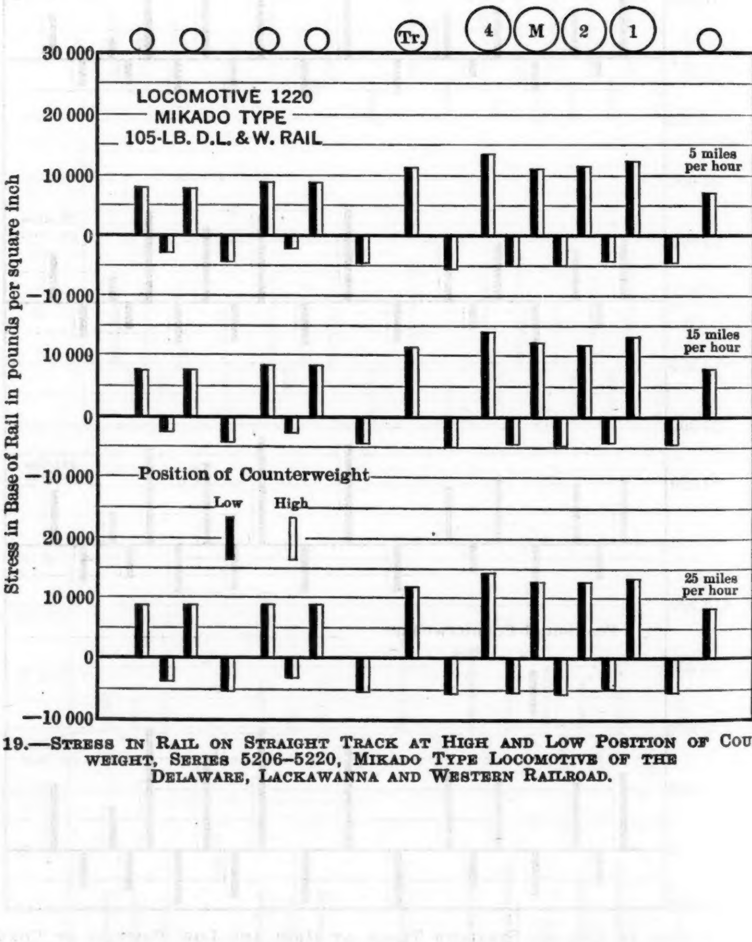


FIG. 19.—STRESS IN RAIL ON STRAIGHT TRACK AT HIGH AND LOW POSITION OF COUNTERWEIGHT, SERIES 5206–5220, MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

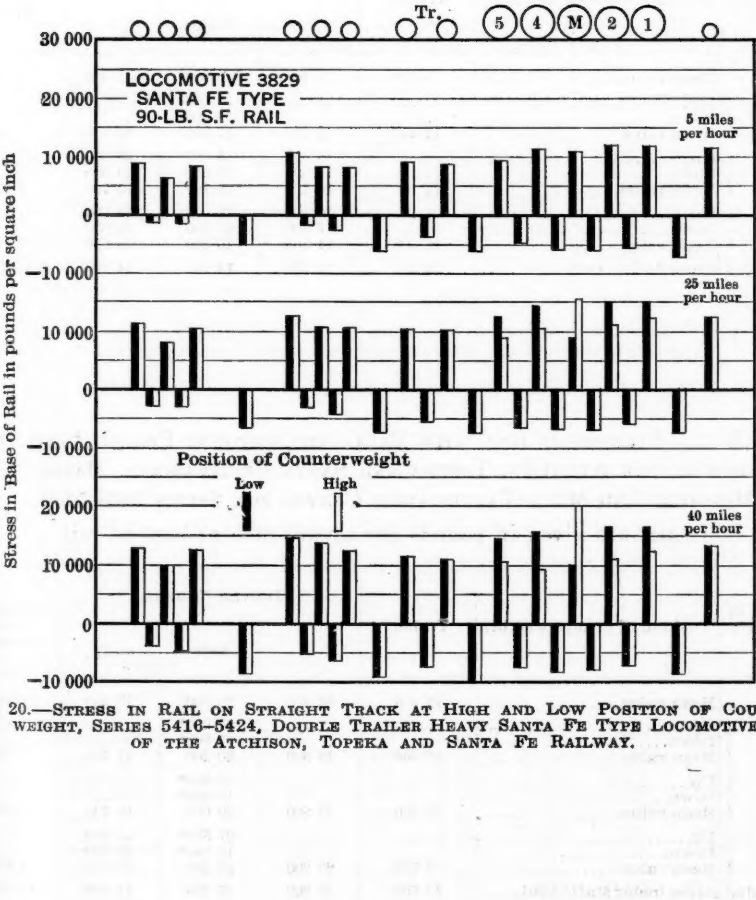


FIG. 20.—STRESS IN RAIL ON STRAIGHT TRACK AT HIGH AND LOW POSITION OF COUNTERWEIGHT, SERIES 5416–5424, DOUBLE TRAILER HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

TABLE 11.—STRESSES IN RAIL WITH LIGHT PRAIRIE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY. MAXIMUM, MINIMUM, AND MEAN VALUES FROM CURVES FOR SERIES 5441-5449.

Stresses are given in pounds per square inch at base of rail.

Speed, in miles per hour.	Position of counterweight.	Trailer.	Driver Number. 3	Driver Number. Main.	Driver Number. 1	Front truck wheel.
5	Mean value	12 600	16 400	16 900	15 800	8 200
25	Up	......	......	15 500	......	......
	Down	......	......	19 500	......	......
	Mean value	12 400	16 100	17 300	16 400	9 600
40	Up	......	13 000	15 000	13 500	......
	Down	......	19 000	20 000	20 000	......
	Mean value	13 100	16 100	16 700	15 700	9 300
50	Up	......	10 500	12 000	12 000	......
	Down	......	17 500	21 000	22 000	......
	Mean value	12 700	14 200	16 400	16 800	9 700
Calculated stress under static load		14 200	13 700	14 000	14 300	10 000

TABLE 12.—STRESSES IN RAIL WITH BALANCED COMPOUND PRAIRIE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY. MAXIMUM, MINIMUM, AND MEAN VALUES FROM CURVES FOR SERIES 5434-5440.

Stresses are given in pounds per square inch at base of rail.

Speed, in miles per hour.	Position of counterweight.	Trailer.	Driver Number. 3	Driver Number. Main.	Driver Number. 1	Front truck wheel.
5	Mean value	15 300	18 400	20 000	15 800	12 500
25	Up	......	......	23 000*	......	......
	Down	......	......	17 000*	......	......
	Mean value	16 800	19 800	20 200	17 400	13 500
40	Up	......	......	23 500*	......	......
	Down	......	......	18 500*	......	......
	Mean value	18 200	19 800	20 000	18 700	15 100
50	Up	......	......	27 500*	17 500	......
	Down	......	......	18 000*	22 500	......
	Mean value	19 700	20 200	21 300	20 000	14 800
Calculated stress under static load		14 700	18 800	15 100	18 700	11 200

* The maximum and minimum occur at the quarter-points.

TABLE 13.—STRESSES IN RAIL WITH MOUNTAIN TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY. MAXIMUM, MINIMUM, AND MEAN VALUES FROM CURVES FOR SERIES 5338-5344.

Stresses are given in pounds per square inch at base of rail

Speed, in miles per hour.	Position of counterweight.	Trailer.	DRIVER NUMBER.				FRONT TRUCK WHEELS.	
			4	3	Main.	1	2	1
5	Mean value	17 000	15 300	13 300	14 000	13 600	4 000	7 500
25	Up	......	......	......	......	......	.....	.....
	Down	......	......	......	......	......	.....	.....
	Mean value	17 400	15 400	13 900	14 100	14 200	3 800	8 000
40	Up	......	14 000	......	......	......	.....	.....
	Down	......	17 000	......	......	......	.....	.....
	Mean value	18 200	15 600	15 400	15 200	14 400	4 000	7 900
60	Up	......	15 000	15 000	20 000	......	.....	.....
	Down	......	20 000	20 000	12 500	......*	.....	.....
	Mean value	19 500	17 200	17 300	17 100	15 900	5 000	8 500
Calculated stress under static load		21 200	14 400	12 100	11 400	14 000	2 800	7 300
Calculated additional stress due to counterbalance at 60 miles per hour		......	+4 700	+3 500	+3 500	+4 700	.....	.....

*Not sufficient tests to determine the stress due to counterbalance.

TABLE 14.—STRESSES IN RAIL WITH LIGHT SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY. MAXIMUM, MINIMUM, AND MEAN VALUES FROM CURVES FOR SERIES 5300-5318.

Stresses are given in pounds per square inch at base of rail.

Speed, in miles per hour.	Position of counterweight.	Trailer.	DRIVER NUMBER.					Front truck wheel.
			5	4	Main.	2	1	
5	Mean value	10 700	8 100	7 100	8 100	11 500	12 100	7 800
25	Up	......	7 500	6 500	13 500	11 500	11 500	......
	Down	......	10 500	10 000	4 500	13 500	15 000	......
	Mean value	11 300	9 500	7 900	9 900	12 600	13 100	8 800
35	Up	......	7 500	5 000	17 500	10 000	19 000	......
	Down	......	13 000	11 500	5 500	17 000	9 500	......
	Mean value	11 600	10 500	8 500	11 500	13 600	14 600	9 200
45	Up	.....	6 000	7 000	23 500	9 500	9 500	......
	Down	......	14 000	14 000	6 500	20 000	22 500	......
	Mean value	11 700	10 200	10 500	14 800	14 600	14 800	10 100
Calculated stress under static load		4 900	10 800	7 900	10 000	8 100	12 200	7 600

TABLE 15.—STRESSES IN RAIL WITH HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY. MAXIMUM, MINIMUM, AND MEAN VALUES FROM CURVES FOR SERIES 5401-5408.

Stresses are given in pounds per square inch at base of rail.

Speed, in miles per hour.	Position of counter-weight.	Trailer.	Driver Number.					Front truck wheel.
			5	4	Main.	2	1	
5	Mean value..........	16 900	15 900	12 200	12 900	10 100	13 400	7 300
25	Up..................	......	......	10 000	......	8 500	......	......
	Down................	......	......	16 000	......	14 000	......	......
	Mean value..........	17 700	16 400	13 600	13 800	11 100	14 200	8 300
40	Up..................	......	15 500	10 500	16 500	10 500	13 000	......
	Down................	......	19 000	20 000	11 500	16 000	20 500	......
	Mean value..........	18 900	17 200	14 700	14 200	12 700	16 300	8 800
Calculated stress under static load..........................		19 700	15 400	11 300	11 000	10 600	14 400	6 700
Calculated additional stress due to counterbalance at 40 miles per hour.....................		......	+3 700	+3 600	−2 800	+3 600	+3 700	......

TABLE 16.—STRESSES IN RAIL WITH DOUBLE TRAILER HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY. MAXIMUM, MINIMUM, AND MEAN VALUES FROM CURVES FOR SERIES 5416-5424.

Stresses are given in pounds per square inch at base of rail.

Speed, in miles per hour.	Position of counterweight.	Trailer.		Driver Number.					Front truck wheel.
		2	1	5	4	Main.	2	1	
5	Mean value..............	9 200	8 900	9 500	11 400	11 100	11 900	11 900	11 700
25	Up......................	....	....	9 000	10 500	15 500	11 000	12 500	....
	Down....................	....	....	12 500	14 500	9 000	15 000	15 000	....
	Mean value..............	10 400	10 100	10 100	12 400	12 200	13 000	13 900	12 400
40	Up......................	....	....	10 500	9 500	20 000	11 000	12 500	....
	Down....................	....	....	14 500	15 500	10 000	16 500	16 500	....
	Mean value..............	11 500	11 100	12 400	12 800	12 900	14 000	14 900	13 300
Calculated stress under static load.		8 700	7 500	12 600	9 500	10 000	11 300	14 500	8 600
Calculated additional stress due to counterbalance at 40 miles per hour..............................		....	....	+3 700	+3 600	−2 800	+3 600	+3 700	....

TABLE 17.—STRESSES IN RAIL WITH PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD. MAXIMUM, MINIMUM, AND MEAN VALUES FROM CURVES FOR SERIES 5136-5149.

Stresses are given in pounds per square inch at base of rail.

Speed, in miles per hour.	Position of counter-weight.	Trailer.	Driver Number.			Front Truck Wheels.	
			3	Main.	1	2	1
5	Mean value.......	15 300	13 700	12 600	12 600	3 300	7 700
25	Up..............	......	......	......	10 000	......	......
	Down............	......	......	......	15 000	......	......
	Mean value......	15 700	14 300	12 400	12 300	4 200	7 900
40	Up..............	......	12 500	......	10 000	......	......
	Down............	......	18 000	......	16 000	......	......
	Mean value.......	16 600	15 000	13 600	13 000	5 200	9 000
60	Up..............	......	12 000	......	11 500	......	......
	Down............	......	20 000	......	20 000	......	......
	Mean value.......	17 400	15 800	15 300	15 700	7 100	10 900
Calculated stress, under static load..................		15 800	14 800	12 200	14 600	1 500	5 400
Calculated additional stress due to counterbalance at 60 miles per hour...........		......	+5 900	+4 500	+5 900	......	......

TABLE 18.—STRESSES IN RAIL WITH MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD. MAXIMUM, MINIMUM, AND MEAN VALUES FROM CURVES FOR SERIES 5206-5220.

Stresses are given in pounds per square inch at base of rail.

Speed, in miles per hour.	Position of counterweight.	Trailer.	Driver Number.				Front truck wheel.
			4	Main.	2	1	
5	Mean value	11 400	13 600	11 100	11 500	12 200	7 000
15	Up	......	......	......	......	......	......
	Down	......	......	......	......	......	......
	Mean value......	11 400	14 100	12 000	11 900	12 000	7 800
25	Up...............	......	......	......	......	......	......
	Down.............	......	......	......	......	......	......
	Mean value......	11 900	14 200	12 500	12 700	13 100	8 200
Calculated stress under static load		12 600	12 200	10 100	10 100	13 000	6 500

Attention should be called to the fact that the stresses given in the diagrams and tables are average stresses, the result of averaging a number of observations, usually a large number, from 50 to 125. This means that many observations lie above the average value and many below it. In fact, when all the observations are plotted for a revolution of a driver, there is a belt of points within two rather definite boundaries, one on each side of the line of averages, as illustrated in Figs. 21 to 25, inclusive. Within these boundaries, the points are fairly well distributed, and outside of them a few scattered points will be found. For straight track, the boundaries of the belt of points may be 5 000 lb. per sq. in. above and below the average line.

From an inspection of the diagrams and tables, it will be noted that at a speed of 5 miles per hour the average stress in the base of rail of the 85-lb. Am. Soc. C. E. section, ranged from 15 800 to 20 000 lb. per sq. in. under the drivers of the Pacific type locomotive and the two Prairie types of the Atchison, Topeka and Santa Fe Railway. On the 90-lb. S. F. rail, the average stress ranged from 10 100 to 15 900 lb. per sq. in. under the drivers of the Mountain type locomotive and Heavy Santa Fe types, at 5 miles per hour. For the Light Santa Fe type, having much lighter wheel loads, the corresponding stresses in the 90-lb. S. F. rail, at the same speed, range from 7 100 to 12 100 lb. per sq. in. For the Pacific and Mikado types of the Delaware, Lackawanna and Western Railroad, the stresses in the 105-lb. D. L. & W. section under the drivers, at 5 miles per hour, ranged from 11 100 to 13 700 lb. per sq. in. It should be borne in mind that the stress named in every case is the average value found in a considerable number of runs and that when a locomotive is run over the track many times, individual stresses will be found under a given wheel that are considerably greater in magnitude than the average stress named. It should also be remembered that the lateral bending of the rail under the action of the locomotive on straight track will result in stresses at the outside or the inside edge of the base of rail that are materially higher than the mean of the stresses at the two edges, and, also, that the effect of speed and counterbalance is to add considerably to the values found at 5 miles per hour.

7.—*Effect of the Locomotive Counterbalance.*—In the second progress report of the Committee the problem of counterbalancing the locomotive is briefly considered.* For clearness of expression, the term, counterweight, is there and here used as the weight applied or added to the driver at a point opposite the crank-pin for the purpose of balancing or helping to balance the rotating and reciprocating parts, and the term, counterbalance, as the general condition of underbalance or overbalance as it exists in a given driver, while counterbalancing is used to refer to the general problem of endeavoring to balance the rotating and reciprocating parts.

The vertical effect of a lack of balance of the rotating parts is to increase or decrease the pressure of the drivers on the rails and to vary the pressure upward on the equalizing levers and the frame of the locomotive. Since the counterweight cannot be made to neutralize both the vertical and the horizontal

* *Transactions*, Am. Soc. C. E., Vol. LXXXIII (1919-20), p. 1415; *Proceedings*, Am. Ry. Eng. Assoc., Vol. 21, p. 652.

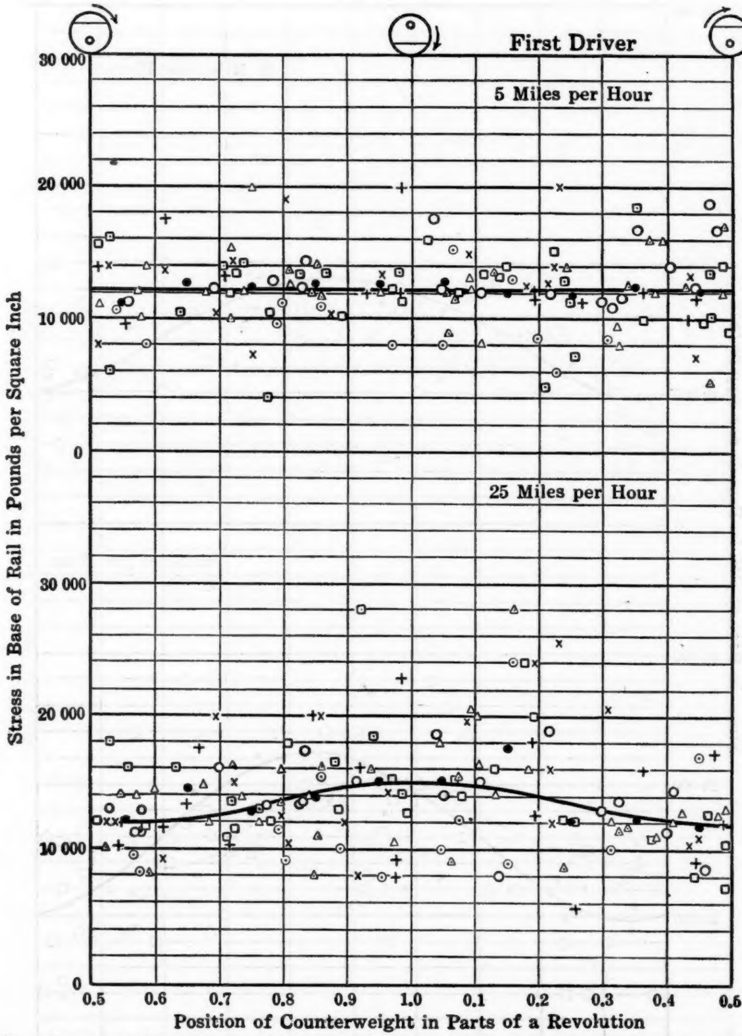


FIG. 21.—OBSERVED VALUES OF STRESS IN RAIL ON STRAIGHT TRACK, SERIES 5300–5318, LIGHT SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

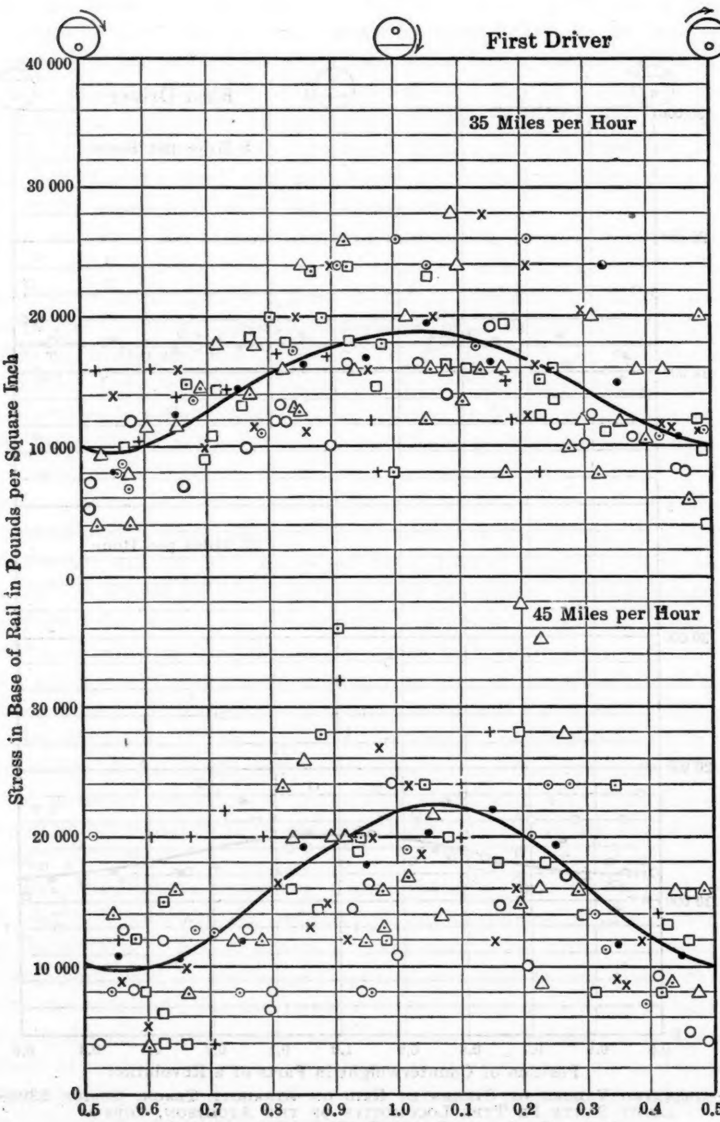


FIG. 22.—OBSERVED VALUES OF STRESS IN RAIL ON STRAIGHT TRACK, SERIES 5300–5318, LIGHT SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

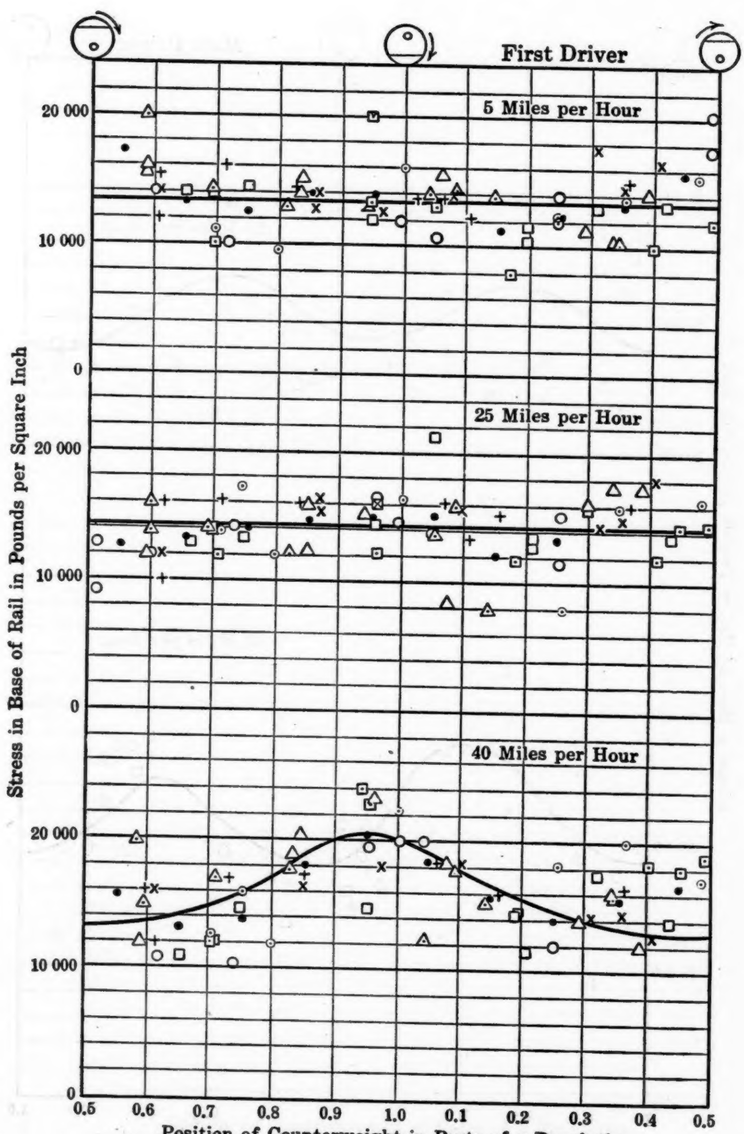


FIG. 23.—OBSERVED VALUES OF STRESS IN RAIL ON STRAIGHT TRACK, SERIES 5401–5408, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

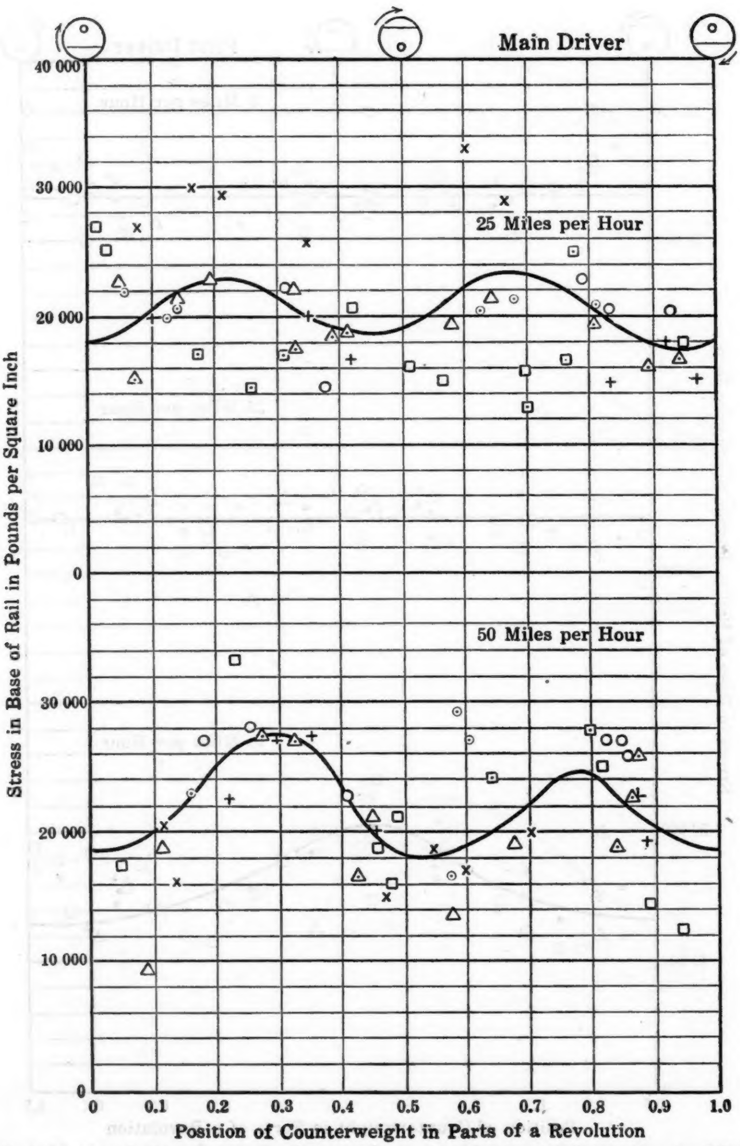


FIG. 24.—OBSERVED VALUES OF STRESS IN RAIL ON STRAIGHT TRACK, SERIES 5434–5440, BALANCED COMPOUND PRAIRIE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

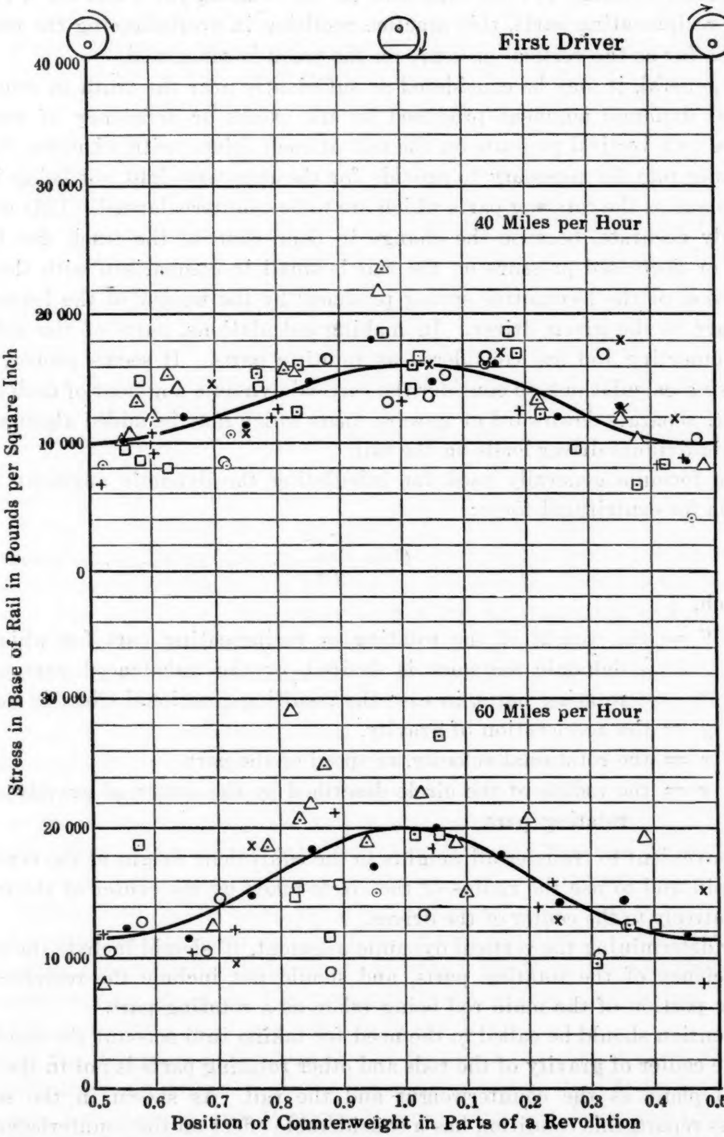


FIG. 25.—OBSERVED VALUES OF STRESS IN RAIL ON STRAIGHT TRACK, SERIES 5136–5149, PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

effect of the moving parts (part of them having horizontal motion only), a compromise must be made in the counterbalancing. It is the common practice in locomotive design to counterbalance for all rotating parts and for a portion of the reciprocating parts, this practice resulting in overbalancing the rotating parts as far as the vertical pressure on the track is concerned.

In general, it may be considered as sufficiently near the truth to count the vertical dynamic augment produced by the excess or deficiency of counterbalance as a vertical pressure on the rail at each driver, with whatever further allowance may be necessary to provide for the counterweight not being in the same plane as the rotating parts which are to be counterbalanced. This method is fairly accurate, because the change in depression of the track due to the added or decreased pressure on the rail is small in comparison with the total depression of the locomotive spring produced by the weight of the locomotive tributary to the given driver. In making calculations, parts of the side rod and connecting rod are considered as rotating parts. It seems proper, then, in making calculations, to consider the vertical dynamic augment of each driver as being separate downward or upward loads which may be added algebraically to the individual driver loads on the rail.

The formula generally used for calculating the dynamic augment is the formula for centrifugal force:

$$C = \frac{W v^2}{g r} \qquad (12)^*$$

in which,

W = the weight of the rotating or reciprocating part for which the dynamic augment is desired, or the unbalanced part of the rotating parts, in case the resulting rotational effect is wanted.

g = the acceleration of gravity.

v = the rotational velocity, or speed of the part.

r = the radius of the circle described by the center of gravity of the rotating part.

It is convenient to transfer all weights to the equivalent weight at the center of crank-pin and to use the radius of the circle taken by the center of the crank-pin relatively to the center of the driver.

For determining the vertical dynamic augment, W should include the excess or deficiency of the rotating parts, and should not include the reciprocating parts, a portion of the main rod being taken as a rotating part.

Attention should be called to the need for taking into account the condition that the center of gravity of the rods and other rotating parts is not in the same vertical plane as the counterweight and the rail. As shown in the second progress report, this condition has a considerable effect on the counterbalancing of the main drivers, but it is not generally important with the other drivers. A main driver with a seeming overbalance for the rotating parts, as judged by the method of calculation generally used in design, may really be an underbalanced wheel, while for an underbalanced main driver, the deficiency in

* *Transactions*, Am. Soc. C. E., Vol. LXXXIII (1919–20), p. 1417.

counterweight may be considerably greater than that expected when this eccentricity of position is not taken into account.

Sample cases of observed values of the stresses in rail throughout the revolution of a driver are plotted in Figs. 21, 22, 23, 24, and 25. The ordinates of the diagrams represent stresses at the base of the rail, in pounds per square inch. The abscissas represent the position of the counterweight at the time the wheel passes over the instrument with respect to its down position, the scale being in fractions of a complete revolution of the wheel. Results given by the several instruments are indicated by individual symbols. The curves representing the stress for a given speed throughout an entire revolution were formed by first averaging the values of the plotted points in groups for each one-tenth of a revolution and then drawing a curve to represent as well as possible the position and trend of these points. As may be expected, at a speed of 5 miles per hour, the variation in stress due to other causes is so much greater than that due to the effect of counterbalance as to mask any effect of counterbalance, and, accordingly, a straight-line average of all the points has been used for all the wheels for a speed of 5 miles per hour. The average of all the observed values, which is approximately the average ordinate for the curves, is called the mean value at the given speed. The difference between this mean value and the high point of the average curve may be taken to be the effect of the counterbalance in increasing the stress (which may be due to overbalance or to underbalance), and the difference in the value to the low point of the curve represents the effect with the counterweight in the opposite position. The position of the counterweight for the maximum and minimum values is also represented on the diagrams.

The same method of determining the average curve of the stress throughout the revolution of a driver was used for all the tests. Figs. 26 to 32, inclusive, give the curves thus found.

As the observations were well distributed throughout the revolution of a driver, the average of the observed values under any wheel at any speed may be taken as the average stress in the rail at that speed without reference to counterbalance effect. The difference between this average stress and the high point and low point of the curve is taken to be the effect of counterbalance.

In Tables 10 to 18, inclusive, are given the stresses with the counterbalance up and counterbalance down and the mean value, and also the calculated additional stress due to counterbalance at one speed, based on the assumed values of counterbalance given in the previous tables, without correction for the outside parts rotating in planes away from the driver.

From the diagrams and tables it will be noted that the highest stress in rail under the main driver in all the locomotives except the Pacific type of the Delaware, Lackawanna and Western Railroad and the Balanced Compound Prairie type of the Atchison, Topeka and Santa Fe Railway occurs when the counterweight is up. For several of the locomotives, a calculation for the counterbalance in the main driver shown in the tables would indicate that, in many cases, the high stress may be expected to occur when the counterweight is down, if the method of calculation is that so generally used of neglecting the

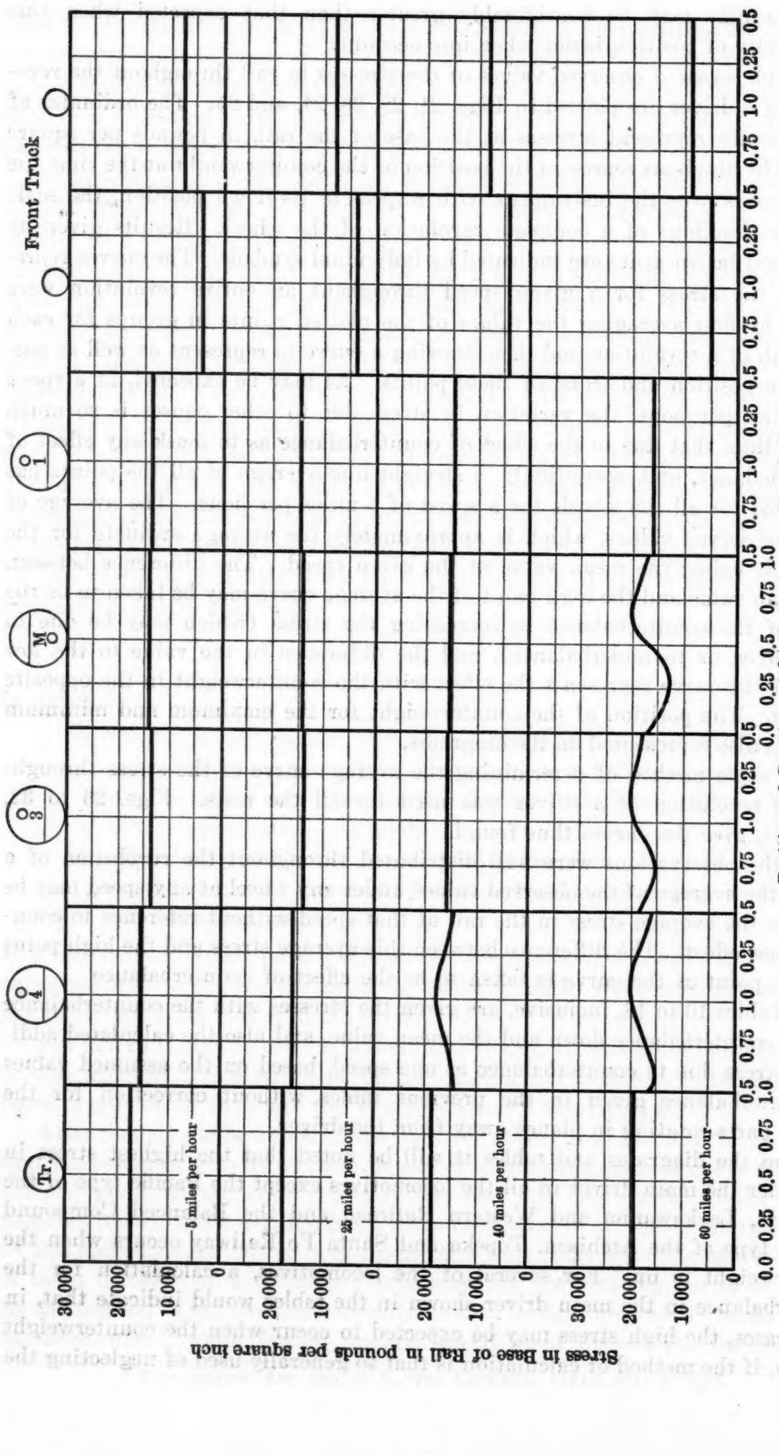


FIG. 26.—CURVES OF AVERAGE STRESS IN RAIL ON STRAIGHT TRACK THROUGHOUT REVOLUTION OF DRIVER, SERIES 5338–5344, MOUNTAIN TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

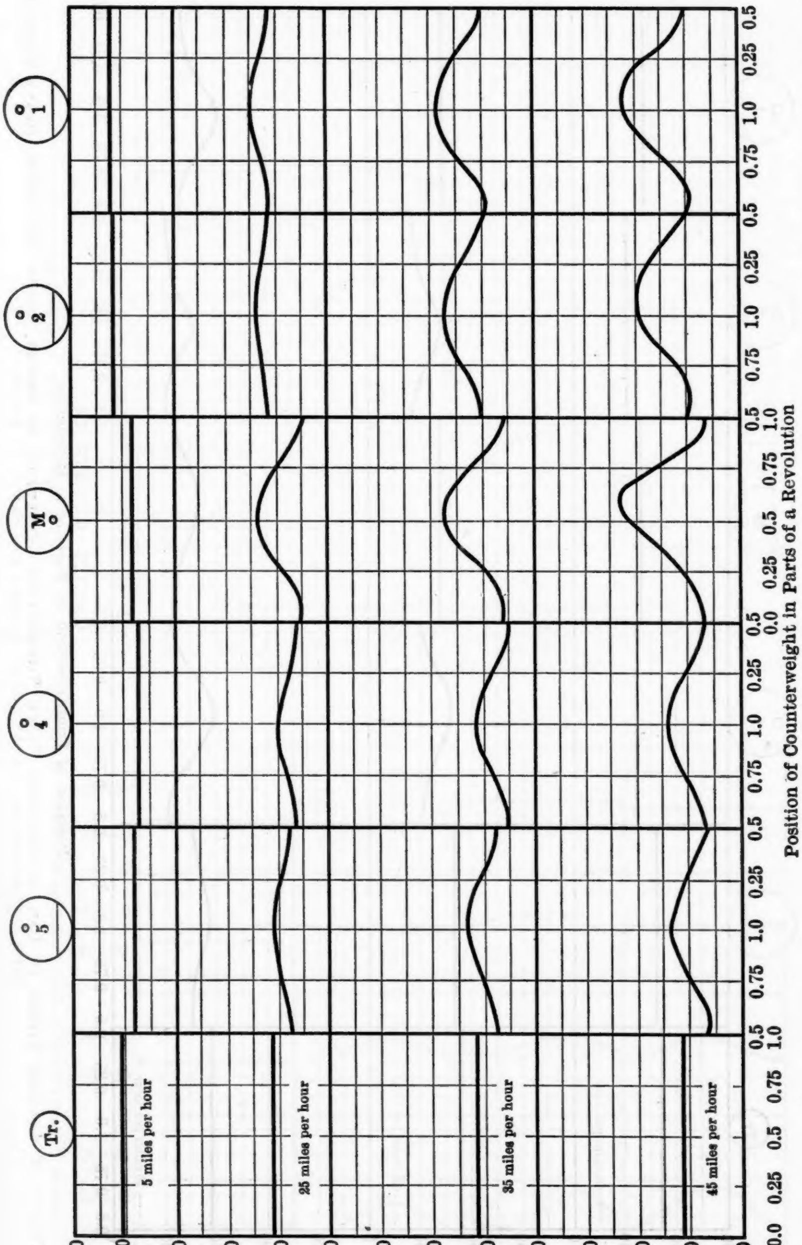


FIG. 27.—CURVES OF AVERAGE STRESS IN RAIL ON STRAIGHT TRACK THROUGHOUT REVOLUTION OF DRIVER, SERIES 5300–5318, LIGHT SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

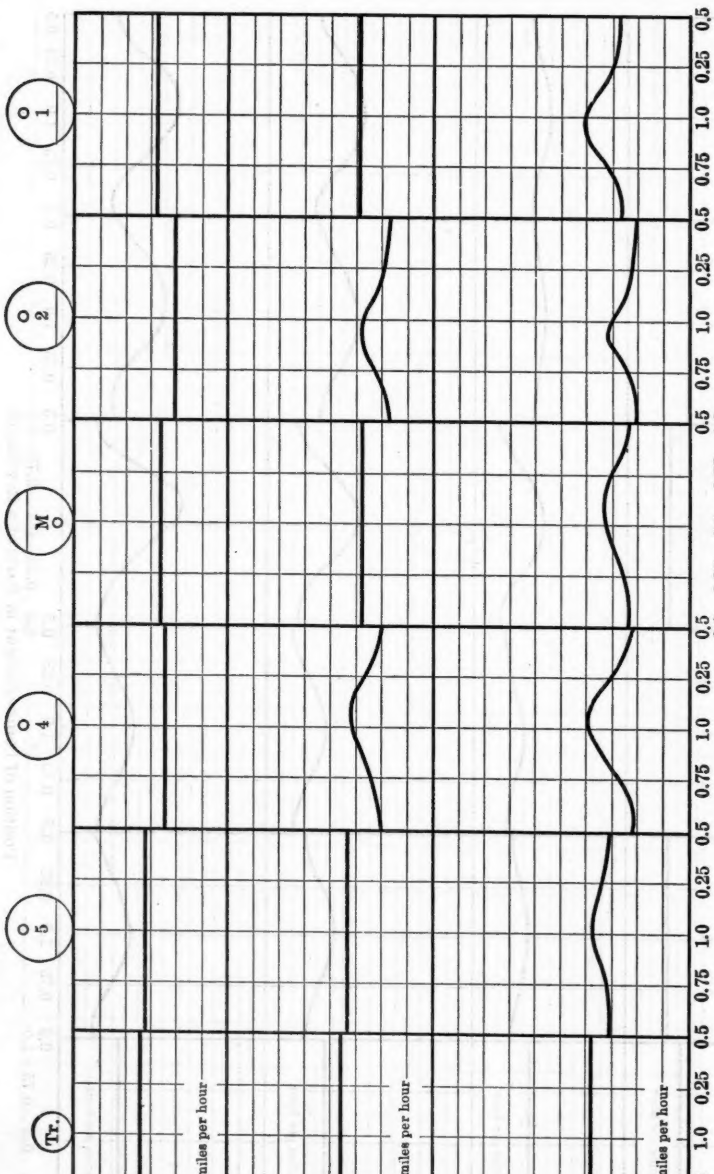


FIG. 28.—CURVES OF AVERAGE STRESS IN RAIL ON STRAIGHT TRACK THROUGHOUT REVOLUTION OF DRIVER, SERIES 5401–5408, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

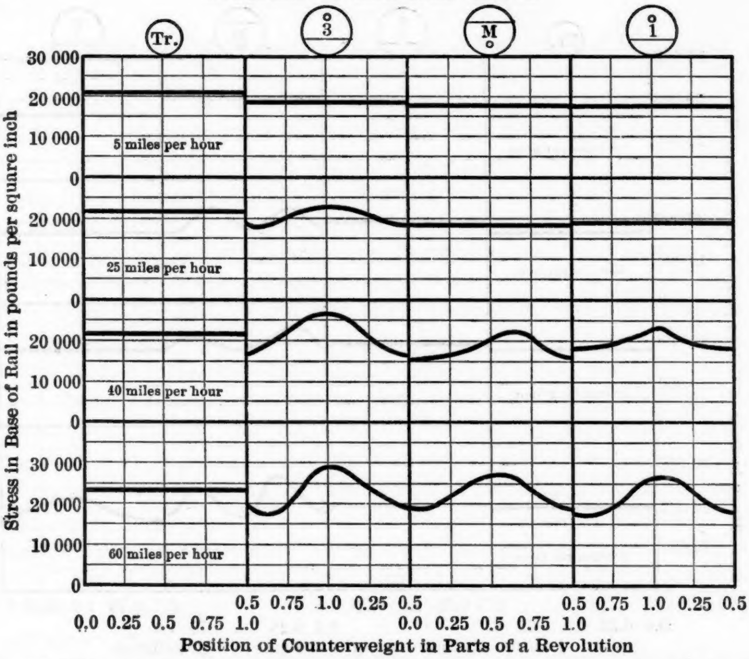


FIG. 29.—CURVES OF AVERAGE STRESS IN RAIL ON STRAIGHT TRACK THROUGHOUT REVOLUTION OF DRIVER, SERIES 5450–5458, PACIFIC TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

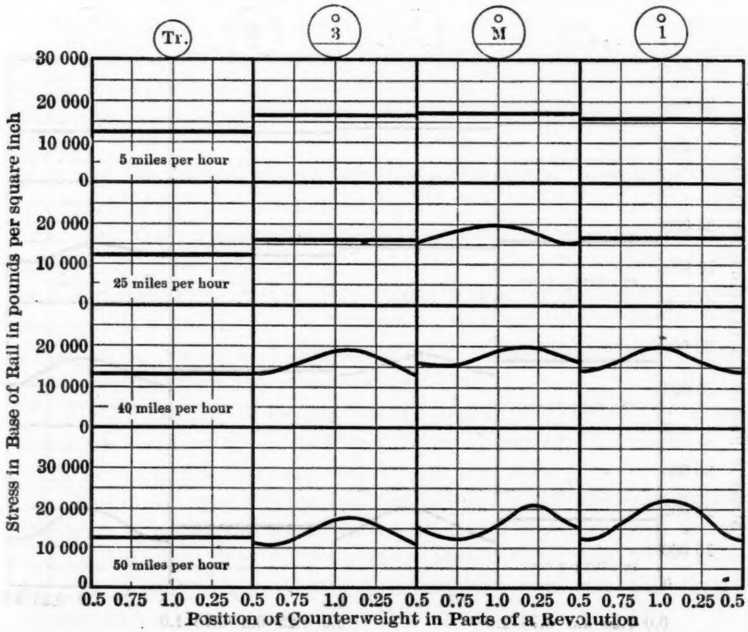


FIG. 30.—CURVES OF AVERAGE STRESS IN RAIL ON STRAIGHT TRACK THROUGHOUT REVOLUTION OF DRIVER, SERIES 5441–5449, LIGHT PRAIRIE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

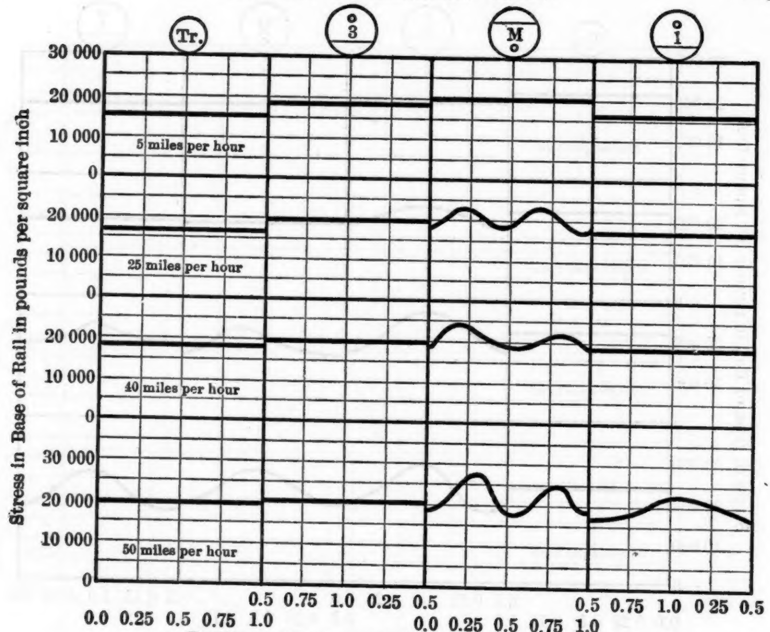


FIG. 31.—CURVES OF AVERAGE STRESS IN RAIL ON STRAIGHT TRACK THROUGHOUT REVOLUTION OF DRIVER, SERIES 5434–5440, BALANCED COMPOUND PRAIRIE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

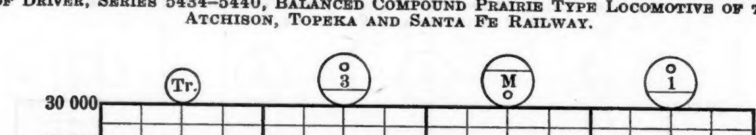


FIG. 32.—CURVES OF AVERAGE STRESS IN RAIL ON STRAIGHT TRACK THROUGHOUT REVOLUTION OF DRIVER, SERIES 5136–5149, PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

effect of the plane of motion of the main rod and other outside rotating parts not being coincident with the plane of motion of the counterweight and wheel and rail, whereas, the opposite condition may be shown by the results. It is evident from the discussion of this subject in the second progress report that a proper consideration of the relative positions of the plane of the rotating parts and of the wheel will account for this seeming contradiction.

Two locomotives of those used have characteristics which differ from those previously described. The Pacific type locomotive of the Delaware, Lackawanna and Western Railroad has no appreciable counterbalance effect under the main driver (see Fig. 25 and Fig. 32); this may be expected from the data of the counterbalance of Table 8. The Balanced Compound Prairie type locomotive of the Atchison, Topeka and Santa Fe Railway has four connecting rods, and there is fair counterbalance when these rods are at the high and low positions. (See Fig. 24 and Fig. 31.) When the counterweight is half way between high and low position, there is an unbalanced effect; at 50 miles per hour, the additional stress due to this effect is 6 200 lb. per sq. in. for one position and 3 400 lb. per sq. in. for the other. The increased stress in rail due to counterbalance in this locomotive is, therefore, greater than that found for the other locomotives except the Light Santa Fe type, and this, notwithstanding it may have been expected that the balanced compound would give low counterbalance effects.

In the case of the Light Santa Fe type locomotive the smallness of the diameter of the wheel prevented the application of sufficient counterweight to the main driver to give a proper counterbalance, even though bobs were used. For the Heavy Santa Fe type locomotive, the counterweight on the main driver was nearly as heavy as that required when all the rotating parts are considered to be in the same plane as the wheel, but the high stress for the counterweight up, shows the need for a revision of such calculations, as do the other locomotives.

A study of the values of the stresses attributable to counterbalance, as given in the tables and diagrams, indicates that these stresses are not unreasonably high, with the exception of the Light Santa Fe type locomotive.

In the Pacific type locomotive of the Atchison, Topeka and Santa Fe Railway, the additional stress in rail attributable to counterbalance at a speed of 60 miles per hour is 5 500 lb. per sq. in. under the third driver, which is 29% of the average stress found at 5 miles per hour. The highest stress under the main driver occurs when the counterweight is up.

In the Light Prairie type locomotive, the highest counterbalance stress at 50 miles per hour is under the first driver, 5 200 lb. per sq. in., which is 33% of the average stress under this driver at 5 miles per hour.

In the Mountain type locomotive, the highest counterbalance stress at 60 miles per hour is under the main driver when the counterweight is up, 2 900 lb. per sq. in., which is 21% of the average stress under this driver at 5 miles per hour. It is well to note that this locomotive rode smoothly and evenly. The counterbalance stresses were unusually small.

The Light Santa Fe type locomotive (an old design, the first of this type), gives relatively high counterbalance effects. Although the driver loads are

small, only about 83% of the wheel loads of the other locomotives tested, the additional stress in rail under the first driver, due to counterbalance, is 7 700 lb. per sq. in., and that under the main driver, 9 200 lb. per sq. in. These counterbalance effects are 64% and 114%, respectively, of the average stresses under these drivers at 5 miles per hour, unusually large counterbalance effects. The observed stresses themselves are not exceptionally high, the rail being relatively heavy for the wheel load of this locomotive, but the stresses indicate very poor counterbalancing. This condition of counterbalance is doubtless due to inability to add adequate counterweight to such small drivers.

For the Heavy Santa Fe type locomotive, the greatest increase in stress in rail due to counterbalance was under the fourth driver, 5 300 lb. per sq. in. at 40 miles per hour, which is 43% of the average stress in rail under this driver at 5 miles per hour. The next greatest counterbalance stress was under the first driver. The greatest stress under the main driver occurred when the counterweight was up. This locomotive rode smoothly and easily even at 40 miles per hour.

For the Pacific type locomotive of the Delaware, Lackawanna and Western Railroad, the greatest increase in stress in rail due to counterbalance was 4 300 lb. per sq. in. under the first driver at 60 miles per hour, which is 35% of the average stress in rail under this driver at 5 miles per hour. The third driver gave about as great counterbalance stress as this at 60 miles per hour. Under the main driver, the counterbalance effect was so small as not to give a definite deviation from a straight-line representation of the tests. This locomotive was, in general, a smooth riding locomotive.

The Mikado type locomotive of the Delaware, Lackawanna and Western Railroad was not run faster than 25 miles per hour on straight track; at the three speeds used, the plotted points showed no counterbalance effect.

In general, for all the locomotives except the Light Santa Fe type, the stresses attributable to counterbalance at the highest speeds run, which in some cases were greater than the scheduled maximum speed allowed for the locomotive, are less than 5 000 lb. per sq. in. and, in most cases, considerably less than this. The counterbalance effect at the highest speeds used may be said generally to be not more than 30 or 40% of the average stress in rail at 5 miles per hour; in some few cases, it runs higher; but, in most cases, it is lower. A counterbalance effect of 30% will not be considered to be excessive, and the only question is whether the scheduled speeds are likely to be exceeded very much. It is seen that an increase of speed of 25% will increase the counterbalance effect by 56% of itself, and an increase of speed of 41% will double the counterbalance effect. It is evident that great care must be exercised to prevent the scheduled limits of speed being exceeded very much if the stresses due to counterbalance are to be kept within moderate bounds. It is also clear that every care should be taken in the design, construction, and maintenance of the proper counterbalance, and checks should be exercised to insure that the conditions of counterbalance are known with certainty, as it has frequently happened that the counterbalance effect has varied from the reported or expected condition. Attention should be given to the main driver and a

careful determination made of the effect of the outside rotating parts not being in the plane of the wheel and counterweight.

In the locomotive for which the weights and positions of the rotating parts seem to be accurately known, the value of the additional stress due to counterbalance, calculated by the use of the calculated vertical dynamic augment, agrees fairly closely with the observed counterbalance stress as found by the method already described. For the main driver, the difficulties are increased, but accurate knowledge of the position of the several outside rotating parts with reference to the plane of the driver itself should permit a fairly close determination of the counterbalance stress under this driver. Any method of design or improvement in materials that will help to keep small the counterbalance effect should be welcomed by both the Mechanical and the Engineering Departments.

8.—Effect of Speed and Combined Effect of Speed and Counterbalance.—If the stresses in rail found in tests made throughout the revolution of a driver are averaged, the effect of counterbalance may be considered to be eliminated. The ratio of this average of the stresses throughout the revolution for a given speed to the average stress at 5 miles per hour may be taken to represent the effect of speed alone. In general, the tests show that the effect of speed on stress in rail under the drivers in all except the Light Santa Fe type locomotive was not large. The speed effect under the leading truck wheels, trailer, and tender wheels is also of interest. The average values of the stress in rail throughout the revolution of the drivers and of the other wheels may be found in the tables and diagrams referred to previously.

In Table 19, the principal values of the percentages of increase in stress in rail under the various wheels of the locomotives, due to increase in speed above 5 miles per hour, are recorded, together with values of the increase due to combined speed and counterbalance effect under the drivers. The general values given represent increases that are common to several wheels, and the maximum value relates to the highest of the group of wheels.

With the exception of the Light Prairie type and the Light Santa Fe type, it will be seen that the general increase in stress in rail under the drivers due to speed alone in changing from 5 miles per hour to the highest speed used in the tests ranges from 15 to 27%, which may be called a moderate and allowable speed effect. With the same exceptions, the maximum speed effect under any one driver ranges from 24 to 30 per cent. For these locomotives and these tracks, therefore, the increase in stress in rail due only to the change in speed noted may be said generally to be less than 35 per cent.

For the combined effect of speed and counterbalance for the same locomotives for the maximum speed used, the range of general total increase in stress in rail is 30 to 53%, and the maximum increase under any driver ranges from 43 to 80 per cent. The stresses in rail at the maximum range from 20 000 to 29 000 lb. per sq. in., in the three sections of rails used. It should be borne in mind that these stresses are the averages of the stresses in the two edges of the base of rail, and, also, that they do not take into account the variations from the average, which are bound to occur, nor the effect of speeds higher than those

normally used. It should be remembered also that the track was substantial track in good condition and that the locomotives were of good design and in good working order.

TABLE 19.—PRINCIPAL VALUES OF INCREASE IN STRESS IN RAIL AT A GIVEN SPEED OVER THE STRESS AT 5 MILES PER HOUR.

The increase is given in percentage of the stress at 5 miles per hour.

Type of locomotive.	Drivers. Speed Alone. General value.	Drivers. Speed Alone. Maximum under one driver.	Drivers. Combined Speed and Counterbalance. General value.	Drivers. Combined Speed and Counterbalance. Maximum under one driver.	Trailer.	Tender Wheels. General value.	Tender Wheels. Maximum under one wheel.
Atchison, Topeka and Santa Fe Railway:							
Pacific, 60 miles per hour	27	30	53	53	15	75	93
Balanced Compound Prairie type, 50 miles per hour	15	26	30	43	29	50	87
Mountain, 60 miles per hour	20, 20	30	35	50, 55	10	40, 60	110
Light Santa Fe, 45 miles per hour	40	77	105	190	10	25	35
Heavy Santa Fe, 40 miles per hour	18, 18, 18	28	50	80	15	75, 70, 50	110
Delaware, Lackawanna and Western Railroad:							
Pacific, 60 miles per hour	20	24	42	59	14	45	57

The increase in stress due to speed alone for the Light Prairie type locomotive by the method of analysis used is very small, much smaller than for the other types of locomotives, and varies from nothing to 5 per cent. No explanation for this is offered. The combined effect of speed and counterbalance (by the method of analysis used, most of which is the effect of counterbalance) is 40% for the first driver and about 20% for the other two drivers.

Although the stresses found with the Light Santa Fe type locomotive at the maximum speed were not exceptionally high, the driver loads being light, and their spacing close, the percentage of increase in stress in rail under the drivers for both speed and combined speed and counterbalance was markedly high. The increase in stress due to speed alone was 47% under the fourth driver and 77% under the main driver; the increase in stress due to combined effect of speed and counterbalance under the several drivers was 87, 74, 190, 97, and 73%, respectively. It may be added that this locomotive was built to be used with a rail lighter than the 90-lb. S. F. rail section that was used in the track tested.

In none of the locomotives tested was the effect of the counterbalance of the drivers transmitted to the trailer in sufficient amount to be brought out in the stress-position of counterweight curves, as was the case in some of the locomotives discussed in the second progress report. The increase in stress under the trailer, due to speed, was, in general, less than that under the

drivers, although the value for the Balanced Compound Prairie type locomotive (27%) was as great as under any driver. In general, the increase noted at the highest speed was from 10 to 15 per cent.

For the locomotives with a two-wheel leading truck, the proportionate increase of stress in rail under the truck due to speed is generally somewhat less than that found under the drivers. The increase in stress at the highest speed is about 20 per cent. For the locomotives with four-wheel leading trucks, the increase under the front wheel is about 35% for the two Pacific type locomotives and 20% for the Mountain type. The increase under the rear wheel is much greater proportionally than that under the front wheel, although as the stress under the rear wheel at static load is very small, because of the proximity of the first driver, the stress at the highest speed is not large, being generally less than that under the front wheel.

The effect of speed on stresses in rail under the wheels of the tender varies with the type of locomotive; the percentage of increase is generally considerably larger than that under the drivers. In the Pacific type of the Atchison, Topeka and Santa Fe Railway and the Heavy Santa Fe type, the increase of stress in rail at the highest speed is approximately 75 per cent. In the other locomotives, the range is from 40 to 60 per cent. The stresses at both 5 miles per hour and at the maximum speed are smaller than the corresponding stresses under the drivers. How much of this large proportional increase in stress is due to the smallness of the wheel diameter and how much to the relatively small load on the wheels or to the way in which the truck is directed and even to the condition of the springs is not known.

9.—General Discussion of Tests on Straight Track.—With the exception of those found with the Light Santa Fe type locomotive, the tests indicate no abnormal stresses in rail under any of the wheels at any speed. The locomotive design is generally within the requirements of what has been considered acceptable practice by Mechanical Departments. With a single exception, the locomotives rode smoothly, showing that there was probably no abnormal strain on the frame of the locomotive. As there are differences in the division of the loads and in the counterbalancing and in the spacing of wheels, some consideration and comparison of the stresses developed in the rail under the various wheels of the locomotives may be useful.

In most cases, the loads on the drivers are moderately heavy, about 30 000 lb. on a driver, reaching 33 000 lb. in the case of the Pacific type locomotive of the Delaware, Lackawanna and Western Railroad. The load on the trailers differs considerably. The leading truck wheels, either two-wheel or four-wheel trucks, each carries about one-half as much load as a driver. Part of the tenders have four-wheel trucks and part six-wheel; the wheel loads of the latter are about the same as those of the former.

The spacing of the drivers is, of course, greater for the Pacific and Prairie types than for the others; the greater spacing results in a somewhat greater proportional effect of the weight on the stresses developed under the drivers. On the other hand, the shorter spacing of the drivers in the Light Santa Fe type locomotive decreases the stresses.

Leaving out of consideration the Light Santa Fe type locomotive of the Atchison, Topeka and Santa Fe Railway and the Pacific type locomotive of the Delaware, Lackawanna and Western Railroad, the latter having heavier driver loads, it is seen that the several locomotives develop stresses under the drivers at 5 miles per hour that do not differ greatly if allowance is made for differences in rail section. Also, there is generally no great difference in stresses for any group of drivers, the stress under the first and last driver naturally being somewhat greater than under the others, as is indicated in Fig. 6* of the first progress report. In the Heavy Santa Fe type locomotive, the stresses vary more, ranging from 10 100 to 15 900 lb. per sq. in. The latter stress, which is under the fifth driver, is even greater than would be expected from analytical considerations (the stress under the trailer being correspondingly less), indicating that the division of load is not that given in the diagram of locomotive loading.

In general, the effect of speed alone (omitting the effect of counterbalance) is as small as could be expected. Even the 27% increase at 60 miles per hour found with the Pacific type locomotive of the Atchison, Topeka and Santa Fe Railway seems moderate. The increase of 18% at 40 miles per hour found with the Heavy Santa Fe type locomotive, compared with the Pacific type locomotive, is directly proportional to the increase of speed, so that this freight locomotive appears to produce about the same relative increase as the passenger locomotive, if the conditions of the track are considered to be the same. It will be seen that the increase at the drivers that show the maximum speed effect, gives somewhat the same comparison, although the increase for one driver of the Santa Fe type (28%) is relatively larger.

The percentage of increase in stress in rail due to counterbalance at the highest speeds used with the different locomotives (see Table 19) generally shows an average for the several drivers that is about the same as the general value for the increase in speed alone. In the case of the Heavy Santa Fe type locomotive, the increase due to counterbalance is greater proportionally than for the other types; this may be due to a poorer opportunity for counterbalancing. The maximum increase due to counterbalance for some one driver of a locomotive is generally considerably greater than the average for the drivers; this shows a need for more careful study of the counterbalancing problem. Further, attention should be called to the discrepancy between the condition of counterbalance in the main driver usually assumed in design and the condition found in the test. This discrepancy was found in every locomotive tested; the difference is explainable at least partly by the neglect to recognize the effect produced by the outside rotating parts not being in the same plane as that of the wheel and rail. It would appear also that the counterbalancing of other drivers of some of the locomotives might be improved. It should be noted also that for speeds still higher than those used the effect of counterbalance may be expected to increase as the square of the velocity.

The general values given in Table 19 for the general increase in stress at the maximum speed used due to combined speed and counterbalance (except

* *Transactions*, Am. Soc. C. E., Vol. LXXXII (1918), p. 1209.

for the Light Santa Fe type as before) range from 30 to 53 per cent. It would appear that these values may be considered to be representative of the increase which may be expected with locomotives of fair design in good condition and with track in good condition. At an individual driver on the Heavy Santa Fe type locomotive, the increase amounts to 80 per cent. If speeds still higher than those used in the tests are likely to be run even occasionally, the fact that the stress in rail will be increased more rapidly than as the first power of the speeds, should receive consideration in judging of the effect on rail and track.

With the exception of the Light Santa Fe type locomotive, the nominal load on the trailer ranges from 72 to 109% of the average load on the drivers. It will be recalled that analytical considerations show that with the trailer well away from the rear driver the stress in rail will be greater accordingly than that under a driver, and that to give an equal stress under static conditions the load on the trailer should be about 75 or 80% of that on a driver. (For an illustration of this effect see Fig. 6 of first progress report.) The observed stresses bear out the relations shown by the analysis except in the case of the Mountain type and the Heavy Santa Fe type locomotive, with which the observed stresses under the trailer, at 5 miles per hour, were 15 to 20% lower than the calculated stresses and the division of load among drivers and trailer was evidently not as reported on the locomotive diagrams, the higher stresses under the drivers indicating that the drivers were taking a greater share of the load than was planned and that the trailer was taking less. The stresses under the trailer of the locomotives of the Delaware, Lackawanna and Western Railroad agreed closely with the calculated values. In four of the types of locomotives used in the tests, the stress under the trailer at 5 miles per hour is greater than the average stress under the drivers. The excess of stress under the trailer over the average stress under the drivers, at a speed of 5 miles per hour, was, as follows: Pacific type, 15%; Mountain type, 22%; Heavy Santa Fe type, 31%; and Pacific type of the Delaware, Lackawanna and Western Railroad, 18%. The increase in stress under the trailer due to speed is generally less than that under the drivers due to speed alone, and when the effect of counterbalance is considered much or all of the discrepancy between the stresses under the trailer and the drivers may disappear, and there will also be the lesser effect of the depression of the track by a single load. It should be recalled that in the tests recorded in the second progress report, there was little difference in effect of speed between trailer and drivers.

For the purpose of comparing the effect of two-wheel and four-wheel leading trucks, the Pacific and Mountain type locomotives, both having four-wheel trucks, may be compared with the Prairie and the Heavy Santa Fe type locomotives having two-wheel trucks. One wheel of the four-wheel truck carries about one-half as much load as a driver, and in the two-wheel truck a wheel also carries about one-half as much as a driver. In the four-wheel truck, the leading wheel develops 50 to 60% as much stress in the rail at 5 miles per hour as a driver; a second wheel produces 25 to 40% as much as a driver, the smaller values under this wheel being due to the proximity of the leading

driver. With the two-wheel truck, the stress in rail under the wheel is 50 to 60% of the stress under a driver. The highest stresses under a truck wheel are found under the leading wheel of the Pacific type locomotive (13 800 lb. per sq. in., at 60 miles per hour) and under the wheel of the Balanced Compound Prairie type locomotive (14 800 lb. per sq. in., at 50 miles per hour). These are not unduly high stresses. Those found with the other types are smaller, but all of them are great enough to insure sufficient pressure on the rail and sufficient depression of rail relative to that under the other wheels to give stable conditions. It would appear that, as far as straight track is concerned, either two-wheel or four-wheel trucks will give stresses in rail which should be considered acceptable; this conclusion allows latitude in the design of the locomotive.

The following locomotives have six-wheel trucks under the tender, Pacific, Mountain, and Heavy Santa Fe types of the Atchison, Topeka and Santa Fe Railway. All the other locomotives tested have four-wheel tender trucks. The weights on the individual wheel when the tender is fully loaded do not differ greatly, ranging from 19 000 to 23 500 lb., except in the Light Prairie type. At the time of the test, the effort was made not to have the loads vary much, water being taken frequently; but the usual load was less than full load. The stresses in rail on straight track at a speed of 5 miles per hour were generally from 8 000 to 10 000 lb. per sq. in., being about two-thirds of those under the drivers. As already noted, the average increase at the highest speed is 40 to 75%, the resulting stress at the highest speed is usually considerably less than the average stress developed under the drivers, although in the Heavy Santa Fe type locomotive the stress under the wheels of the tender at the highest speed reached (about 16 000 lb. per sq. in.) almost as great a value as the average stress under the drivers. The great variation in the effect of speed under the wheels of the tenders of the various locomotives agrees with the results noted in the second progress report. It seems that there must be considerable difference in the design and construction of tenders or in their maintenance.

The placing of a double trailer (two trailer axles) under a Heavy Santa Fe type locomotive for the purpose of learning experimentally the effect of this form of construction in changing the stresses in rail under the trailers and under the drivers was a novel undertaking that gave results of much interest. Although the double trailer was put in one of the regular locomotives and thus the design did not have all the proportions which would be desired in a new design, it gave very successful results and decreased the stresses under both drivers and trailer, at the same time working smoothly and satisfactorily. The introduction of the double trailer brings a marked change in the distribution of stress under the several wheels of the locomotive. The stress under the trailer in the 90-lb. S. F. rail is changed from 16 900 lb. per sq. in. in Locomotive No. 3813 to 9 000 lb. per sq. in. under each trailer in Locomotive No. 3829. Considerable load has evidently been removed from the last three drivers, as the stress, at 5 miles per hour, was decreased 40% under the fifth driver. With these changes has come an increase of 60% in the stress under

the wheel of the front truck, although the resulting stress is not especially high on the straight track. Under the trailers, the effect of speed is to increase the stress 25%, in the change from 5 to 40 miles per hour. Even at 40 miles per hour, the stress in the 90-lb. S. F. rail under the trailers is only 11 300 lb. per sq. in. and the stresses under the drivers (not including the effect of counterbalance) are only about 13 700 lb. per sq. in. The stresses indicate a smoothly running locomotive on straight track. It develops, however, that the presence of two trailer axles does not give adequate room or load to permit the addition of booster equipment, which is now desired with this type of locomotive.

Another locomotive not included in the preceding discussion is the Light Santa Fe type. It differs from most of the other locomotives in having lighter driver loads and in having nominally a very light load on the trailer. The spacing of the drivers is somewhat closer and the trailer is only 7 ft. away from the fifth driver. All these differences favor the development of small stress in the rail. At 5 miles per hour, the stress under the first driver is more than 50% greater than that under the third, fourth, and fifth drivers. The stress under the trailer is double that calculated from the weight given on the locomotive diagram. It is evident that the weights are not distributed as given in the diagram; the average of the observed stresses under drivers and trailer, however, closely agrees with the average of the calculated values. This locomotive is marked by large increase in stress in rail under the drivers, due to both speed and counterbalance. A change in speed from 5 to 45 miles per hour increases the stress in rail under the main driver 77% for speed effect alone, and 113% for counterbalance alone, the combined effect for speed and counterbalance being an increase in stress of 190 per cent. Due to the lighter loads and close spacing of the wheels, the stresses in rail, even at 35 miles per hour, are less than 20 000 lb. per sq. in. in the 90-lb. S. F. rail. At 45 miles per hour, higher stress is found. This is a rough riding locomotive. Its behavior in causing lateral bending of the rail, which is discussed subsequently, and the high increases in stress with increased speed are undesirable features, although it should be noted that the first of these locomotives were built in 1902 and were the first of the 2-10-2 Class built by any road.

The calculation of stresses in rail by the analytical method given in the first progress report in general gives results which agree closely with the observed stresses at 5 miles per hour. The calculated stresses are given in Tables 10 to 18, inclusive. In some cases, the stress under one wheel is higher and that under another is lower, but the average of the stresses under all the wheels checks closely, indicating slight differences between the actual and the nominal distribution of load among the drivers. In one or two cases, the distribution of load evidently differs from the nominal values. Some change in distribution is sometimes seen when the speed is increased. This agreement of values should give added confidence in the accuracy of the analytical mthod.

10.—Stresses at the Two Sides of the Locomotive.—In view of the experience with one of the locomotives reported in the second progress report, it was thought desirable to make a study to learn whether the stresses in the

rail on one side of the locomotive differ from those on the other side. Tests with three locomotives were made on straight track with four instruments on the south rail and four instruments directly opposite on the north rail. During the first day, the locomotive was run eastward at the several speeds, and during the second day, its direction was reversed and runs were made over the same track at the same speeds. The instruments were left on the rail over night and other conditions remained the same. The four instruments on the south rail of the eastward runs were averaged with the four instruments of the north rail

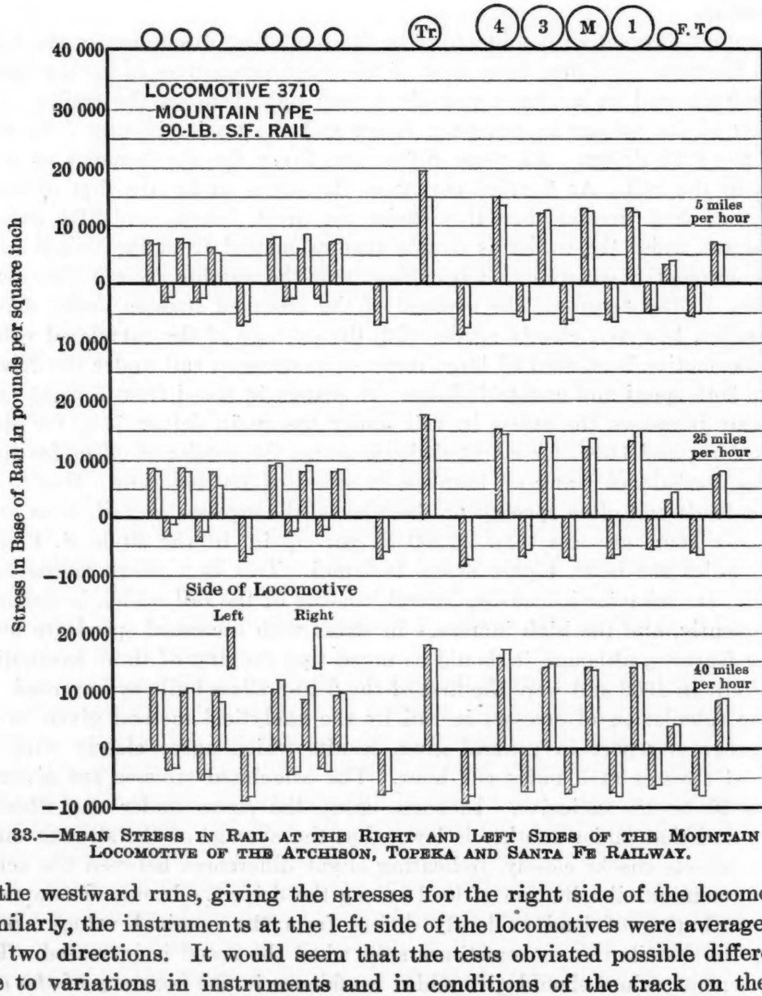


Fig. 33.—Mean Stress in Rail at the Right and Left Sides of the Mountain Type Locomotive of the Atchison, Topeka and Santa Fe Railway.

of the westward runs, giving the stresses for the right side of the locomotive. Similarly, the instruments at the left side of the locomotives were averaged for the two directions. It would seem that the tests obviated possible differences due to variations in instruments and in conditions of the track on the two sides, and that, therefore, the results of the tests for the two sides of a locomotive may properly be compared.

In Fig. 33, the stresses under the sides of the Mountain type locomotive are given. It is seen that the stresses under the left side are nearly the same

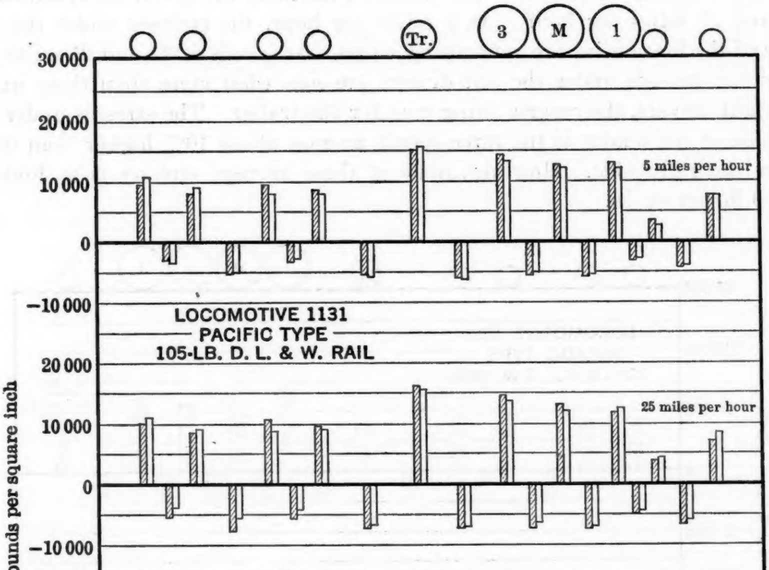


FIG. 34.—MEAN STRESS IN RAIL AT THE RIGHT AND LEFT SIDES OF THE PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

as those under the right side. The only variation of any amount is under the trailer at 5 miles per hour.

In Fig. 35, the stresses under the two sides of the Mikado type locomotive of the Delaware, Lackawanna and Western Railroad are given for speeds of 5, 15, and 25 miles per hour. At 5 miles per hour, the stresses under the two sides of the locomotive are very nearly equal. At speeds of 15 and 25 miles per hour, the stresses under the left drivers are somewhat more than those under the right drivers, the reverse being true for the trailer. The stresses under the left side of the tender at the three speeds average about 10% higher than those under the right side. However, none of these average stresses is as high as 15 000 lb. per sq. in.

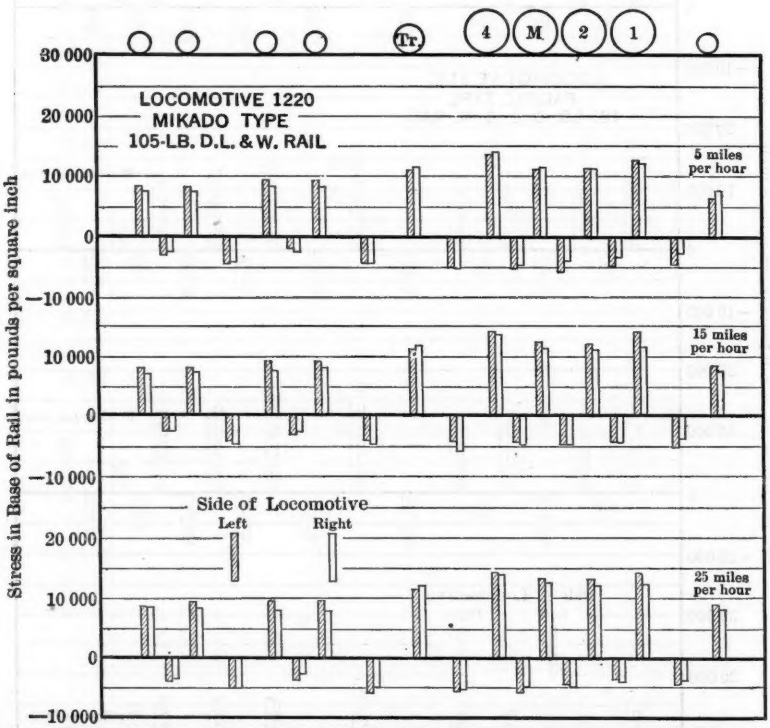


FIG. 35.—MEAN STRESS IN RAIL AT THE RIGHT AND LEFT SIDES OF THE MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

Fig. 34 presents the results under the two sides of the Pacific type locomotive of the Delaware, Lackawanna and Western Railroad at speeds of 5, 25, 40, and 60 miles per hour. At the speeds of 5, 25, and 60 miles per hour, the stresses under the two sides of the locomotive and tender average approximately the same, but at the speed of 40 miles per hour the stresses under the left side averaged about 10% more than those under the right side. None of the average stresses is greater than 18 000 lb. per sq. in.; in no case does the stress under the right and left wheel of an axle differ more than 2 000 lb. per sq. in. and, generally, the difference is much less.

It may be said then that for both types of locomotive the stresses in rail under the two sides of the locomotive were found to differ only slightly. It appears that it more frequently happens that the stress under the left wheel of an axle is somewhat greater than that under the right wheel than the reverse; about two times out of three the stress at the left side is greater than that at the right. There seems to be no noticeable difference in this relation at the lower and the higher speeds, so that the variation found with these engines is not caused by speed or counterbalance. Besides, the tender wheels show the same general variation as the wheels of the locomotive. It seems probable then, that, in these locomotives, the variations between the stress in the rail at the left and the right sides are no more than are to be expected with any well-built machine.

11.—Stresses at the Two Edges of the Base of Rail.—In the two preceding progress reports, reference was made to the frequent and common lateral bending of the rail in straight track, and it was shown that the stresses due to such bending attain considerable magnitude. The data of the tests described in this report give added information on the subject.

In Fig. 36 is plotted the ratio between the stress at the outside edge of rail and the average of the stresses at the two edges (mean stress in base of rail) for each observation under the first pair of drivers of the Light Santa Fe type locomotive and at three speeds. The ratio of the stress at the inside edge of rail to the mean stress in base of rail may be found by subtracting from 2 the ratio given in the diagrams. It should be noted also that the ratio of stress at the outside edge to that at the inside edge may be found by dividing one of these ratios by the other. The value of the stress which corresponds to an observation that gives a ratio of 1.00 is the same as the average stress for the given wheel as it is recorded in the diagrams and tables of general stress values. A mean line drawn through the average of the ratios is also shown. Fig. 36 also gives the stresses at the inside edge and at the outside edge for the same drivers. Fig. 37 gives similar data for the first pair of drivers of the Heavy Santa Fe type locomotive. Table 20 gives values of the average ratio of the stress at the outer edge of rail to the average stress at the two edges for some of the wheels of several locomotives.

A study of these diagrams (confirmed by an examination of the diagrams of the other wheels, which are not reproduced) shows considerable variation between the stresses at the two edges. The stress at the outer edge of the base of rail is quite frequently 33% or more greater than the mean stress in base of rail, in a few cases reaching an excess of 50% or more, and this holds true throughout the revolution of the driver. A stress at the inner edge 33% greater than the mean stress and even more was found, although less frequently. This means that in these cases the stress at one edge of the base is twice as much as that at the other, or more.

Another way of considering the range in stress at the two sides of the rail, which seems useful in judging of the amount and effect of lateral stresses, is that of noting, for any wheel, the range of stress on each side of the mean line in a diagram, such as Fig. 36 or Fig. 37. It will be seen that usually the

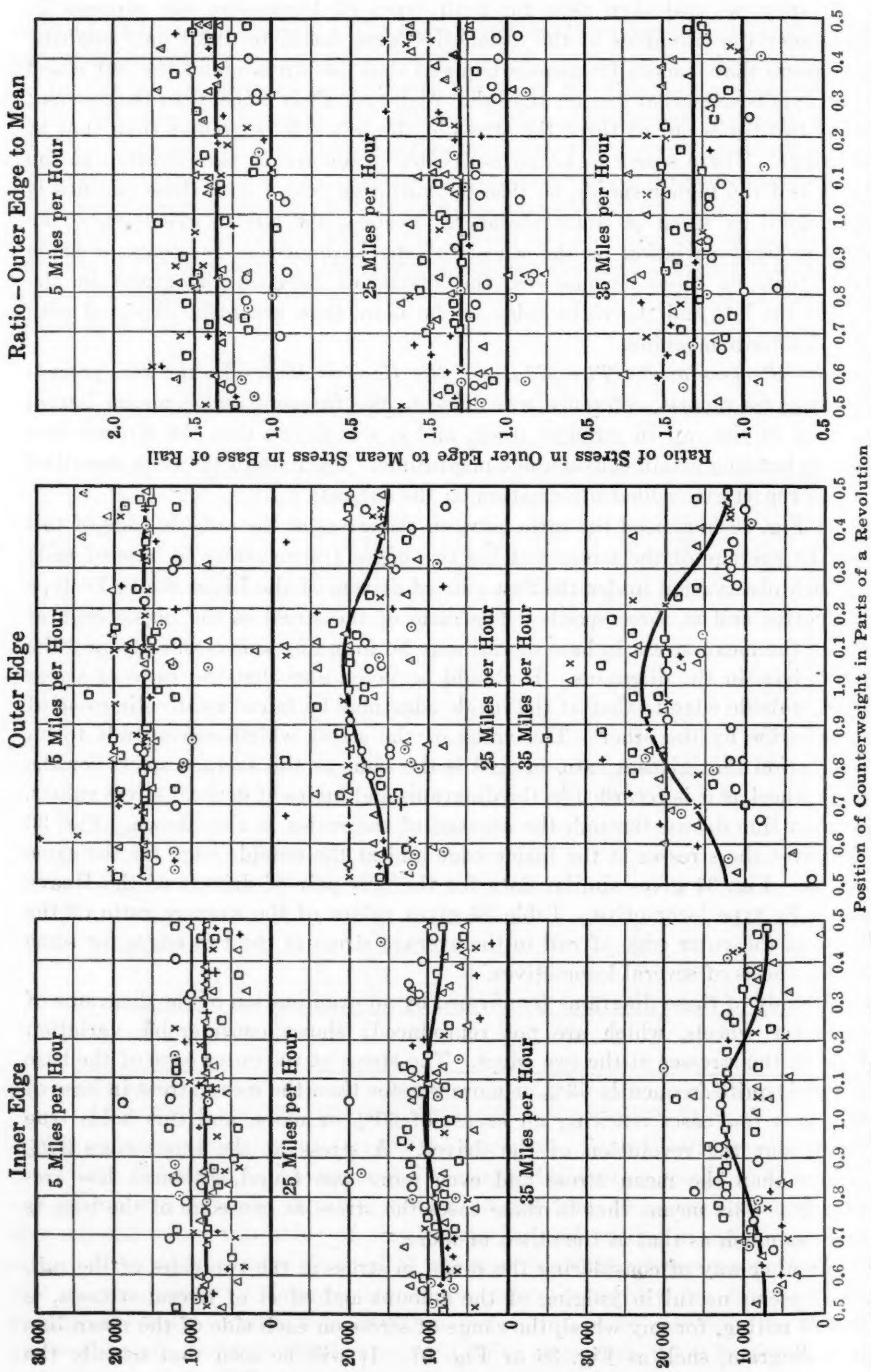


FIG. 36.—STRESSES AT INNER EDGE, OUTER EDGE, AND RATIO OF STRESS IN OUTER EDGE TO MEAN STRESS IN BASE OF RAIL THROUGHOUT THE REVOLUTION OF THE FIRST DRIVER OF THE LIGHT SANTA FE TYPE LOCOMOTIVE ON STRAIGHT TRACK.

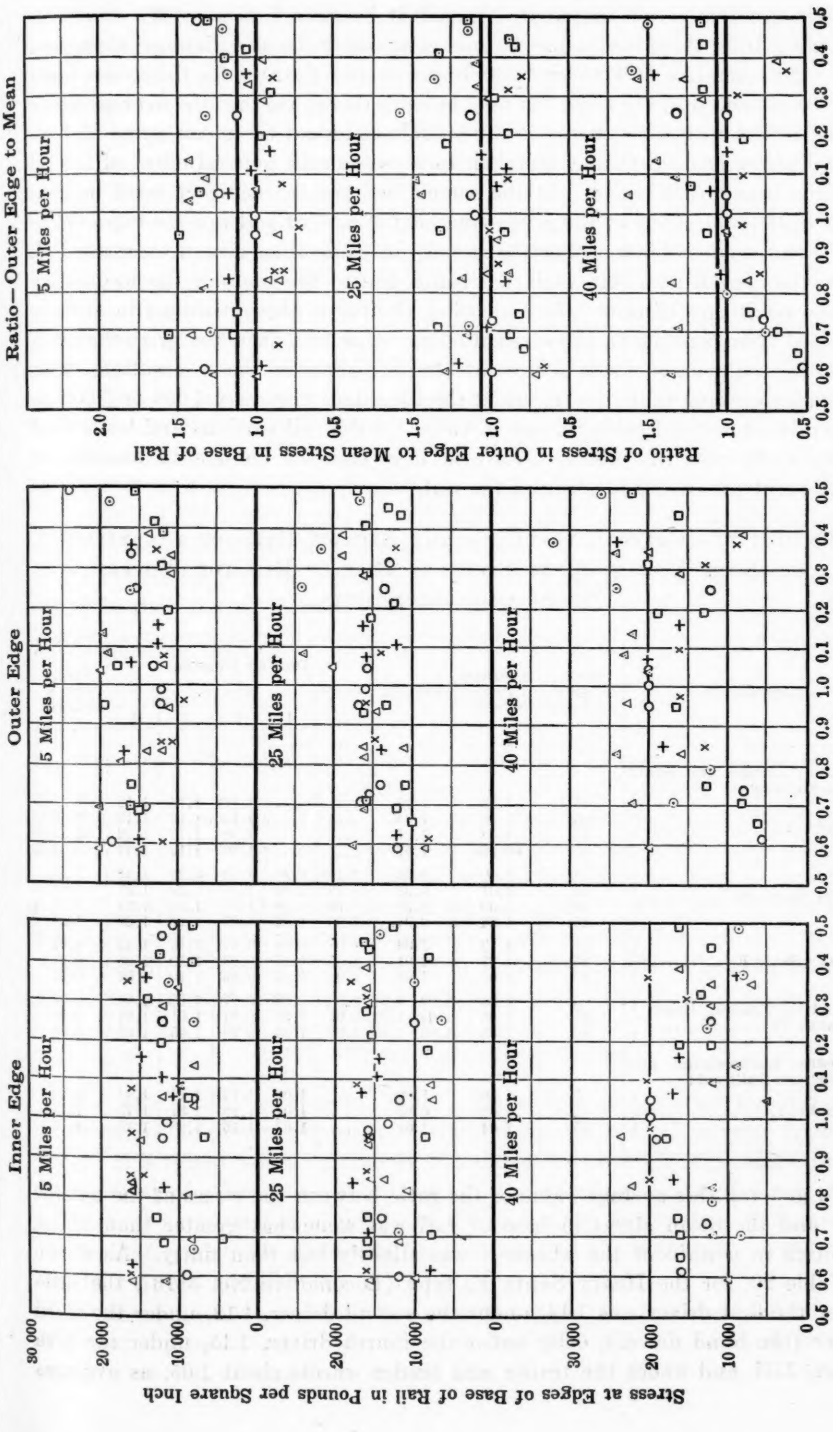


FIG. 37.—STRESSES AT INNER EDGE, OUTER EDGE, AND RATIO OF STRESS IN OUTER EDGE TO MEAN STRESS IN BASE OF RAIL, THROUGHOUT THE REVOLUTION OF THE FIRST DRIVER OF THE HEAVY SANTA FE TYPE LOCOMOTIVE ON STRAIGHT TRACK.

FIG. 36.—STRESSES AT INNER EDGE, OUTER EDGE, AND RATIO OF STRESS IN OUTER EDGE TO MEAN STRESS IN BASE OF RAIL THROUGHOUT THE REVOLUTION OF THE FIRST DRIVER OF THE LIGHT SANTA FE TYPE LOCOMOTIVE ON STRAIGHT TRACK.

stresses are fairly well distributed in a belt between limits on the two sides of a mean line; these limits may be said generally to be at a distance above and below the mean line of 4 000 or 5 000 lb. per sq. in. of stress, for the stresses and rail sections used in the tests. It may be said, therefore, that the average value of the ratio between the stress at the outside edge and the mean stress in base of rail under any wheel may be taken to represent the general effect of lateral bending under that wheel. At the same time, the further fact must be considered, that the stress at the given edge of the base of rail may be expected to vary from a value 4 000 or 5 000 lb. per sq. in. more than this mean stress to a value that much less, this variation being due to the manner the locomotive applies itself on different runs and being similar to the variations in stresses expected from bending in the vertical plane. One may then deal with the average ratio and average stress at the outside edge given by the observations, with the understanding that the stresses at the two edges may vary 4 000 or 5 000 lb. per sq. in. above and below the mean value for the rail sections and loads used in the tests, and that these variations may cause a change in amount or direction of the lateral bending of the rail.

TABLE 20.—General Values of the Average Ratio of the Stress at Outer Edge to Mean Stress in Base of Rail for Wheels of Several Locomotives.

Locomotive.	Speed, in miles per hour.	Average of tender wheels.	Trailer.	Driver Number.					Front truck wheels.
				5	4	3	2	1	
Atchison, Topeka and Santa Fe Railway:									
Pacific	5	1.08	1.05	....	....	1.17	1.14	1.12	1.08 1.01
	25	1.06	1.04	....	....	1.14	1.12	1.12	0.96 1.05
	40	1.03	1.07	....	....	1.08	1.10	1.12	1.05 1.05
	60	0.99	1.07	....	....	1.08	1.13	1.17	1.08 1.01
Light Santa Fe	5	1.00	0.96	1.10	1.10	1.01	1.26	1.33	1.05
	25	1.01	0.97	0.99	1.06	1.05	1.29	1.31	1.04
	35	1.00	0.99	0.96	1.09	1.05	1.24	1.31	1.00
	45	1.04	0.94	1.00	1.02	1.07	1.27	1.20	1.04
Heavy Santa Fe	5	1.13	1.03	1.08	1.18	0.97	1.16	1.12	1.01
	25	1.07	1.01	1.05	1.15	0.93	1.10	1.06	0.97
	40	1.00	1.05	1.03	1.13	0.89	1.10	1.06	0.97
Double Trailer, Heavy Santa Fe	5	1.03	1.02 0.98	0.96	0.98	0.97	1.00	1.05	0.97
	25	1.05	1.04 1.01	0.97	0.98	0.94	1.01	1.01	0.96
	40	1.05	1.05 1.05	1.08	1.05	0.99	1.05	1.07	1.04
Delaware, Lackawanna and Western Railroad:									
Mikado	5	1.06	1.00	....	1.06	1.14	1.24	1.17	1.20
	15	1.05	0.96	....	1.04	1.18	1.31	1.15	1.14
	25	1.04	1.01	....	1.07	1.16	1.23	1.13	1.13

In general, this average value of the ratio between the stress at the outside edge and the mean stress in base of rail was somewhat greater than unity, although in certain of the wheels it was slightly less than unity. As shown in Table 20, for the Heavy Santa Fe type (Locomotive No. 3813), the ratio under the first driver was 1.14, under the second driver, 1.12, under the third driver (the blind driver), 0.93, under the fourth driver, 1.15, under the fifth driver, 1.05, and under the trailer and tender wheels about 1.05, as averages

for the several speeds. Locomotive No. 3829 gives ratios nearer to unity. It appears that in locomotives of the same class the condition of the tires or other parts has much to do with the amount of the lateral bending of the rail. It is also apparent that different wheels of a locomotive produce lateral bending stresses of quite different magnitudes. At the blind driver, there seems usually to be less outward bending stress than at other drivers. The ratio for the trailer is only a little greater than 1.0.

The first and second drivers of the Light Santa Fe type locomotive present illustrations of very marked outward lateral bending of rail, the ratio of stress at the outside edge of base of rail to mean stress at the first driver being 1.33 at the speed of 5 miles per hour. The ratio for the main driver and the trailer do not vary greatly from 1.00, being 1.01 and 0.96, respectively, at the speed of 5 miles per hour, indicating about as much lateral bending inwardly as outwardly. The average ratio under the first driver is markedly greater for the left rail than for the right. Whether this is due to differences in the condition of the tread of the two drivers on the same axle, to the difference in time of stroke of the two pistons, or to other causes, is not known. There is no marked difference in the amount and nature of the lateral bending of the rails at the two sides of the other locomotives.

As the lateral bending strength of the rail is less than the vertical bending strength, the bending moment corresponding to a given fiber stress is less for lateral bending than for vertical bending. The section modulus, $\frac{I}{c}$, for bending in a vertical plane for the rail sections used is about five times that for bending in a horizontal plane. For a ratio of stress at the outside edge to mean stress with a value of 1.33, it is seen that the lateral bending moment in rail is about 7% of the vertical bending moment required to develop the mean stress in the base of rail. A value of the lateral bending moment found quite frequently is 4% of the vertical bending moment, although in a few cases it reached 14%, if the effect of the added 5 000 lb. per sq. in. of the belt of stresses is taken into consideration. From a study of the observed values, it would seem that in designing a rail section for straight track a lateral bending moment at least equal to 14% of the vertical bending moment should be provided for.

III.—Tests on Curved Track

12.—The Action of Curved Track.—In traversing a curve, the action of a locomotive or car on the rail and track differs in several respects from the action on straight track. Some of the differences are of importance in the development of stresses in the rail and in the effect on the track structure as a whole. The principal elements of the action of locomotives and cars on curves that need to be considered in the study of the action of curved track may be outlined as follows:

1.—Since the outer rail is longer than the inner one, the wheel on the outer rail must slip backward, or the wheel on the inner rail slip forward, or both, to overcome the difference in travel; this motion of itself may be expected

to be accompanied by a force which acts in a longitudinal direction along the rail rather than laterally, and thus does not produce bending in the rail, although it may modify the magnitude of the force required to produce lateral slipping and hence indirectly affect the magnitude of the lateral bending force.

2.—As the driving wheels of a locomotive, and the wheels of a truck having more than one axle, are grouped in a frame of some stiffness, a lateral movement is involved in changing the direction of the motion of the group of wheels in traversing a curve, and this involves a slipping of one or more pairs of the forward wheels in a lateral direction inwardly of the curve and, generally, of one or more pairs of the rear wheels in a lateral direction outwardly. This action develops lateral pressures against both the inner and the outer rail. A lateral force is thus present at one or more wheels even when the speed is that corresponding to the super-elevation of the track. The lateral pressure thus developed may be of considerable magnitude.

3.—The lateral pressure at two or more of the drivers has been found to give a large increase in the stress at one edge of the base of rail. By reason of the lateral inclination of the track and the centrifugal force developed at the given speed, the division of load between the two rails will not be the same on curved track as on straight track, except at the one speed corresponding to the speed of super-elevation; and, even at that speed, generally the load will not be divided equally between the two wheels of most of the axles. It will appear, also, that there are transfers of load from one rail to the other that are due to other causes.

4.—For some reason, the action of the system of equalizing levers and springs of the locomotive is not the same on curves as on straight track; at least, a much greater vertical bending stress is found in the inner rail under one of the intermediate drivers than under the others, especially at low speeds, and the abnormal action of the equalizers and springs may be one explanation for this. It is also true that a greater vertical bending stress is frequently found in the outer rail under the front driver than under the other drivers, the difference in both cases varying with the speed. This excess of stress under some of the drivers must be due to a large increase of load carried by these drivers.

5.—An effect of the lateral inclination of the track and the presence of centrifugal force is the development of a lateral pressure against the rails; the amount of this lateral pressure may not be equally divided between the two rails or even among the several drivers on one side of the locomotive.

6.—For sharp curves (curves of relatively small radius), there may be a spreading action on the track caused by the flanges bearing against the inner and outer rails; the lower limit of degree of curve above which this spreading action may be expected to become important will depend on the length of wheel base and on the difference between the wheel gauge and the gauge of the track. For the curves in ordinary use, other sources of lateral pressure against the rail appear to be much more important. The several elements of the problem noted will now be considered somewhat more fully.

a.—Difference of Length of Outer and Inner Rail

It is shown by Wellington* that the longitudinal slipping of the wheels of a freight-car truck necessary to overcome the difference in length of the outer and the inner rail of a curve in some cases may occur on the outer rail and in others on the inner rail, although usually not by both wheels of an axle at the same time, as that wheel will slip which will slip more easily, and a slight variation in either the load or the coefficient of friction will give one wheel or the other an advantage in this respect. Wellington further states that either the super-elevation or the centrifugal force is alone competent to produce enough inequality of load to effect a difference and that one wheel having begun to slip is likely to continue so to do for some time, although it may not be the same wheel for two consecutive axles and change from one to the other wheel may take place from time to time. As most of the drivers of a locomotive will be found to be slipping in a lateral direction continually, the matter of the difference between the coefficient of friction for rest and motion will not enter into the question of whether the wheel will have longitudinal slip to the extent that might otherwise be expected from Wellington's analysis for freight-car trucks. The fact that the drivers are coupled together by the side rods is an added feature which may make the action of locomotive drivers differ from that of car trucks. Wellington also shows that the coning of the wheels does not overcome the difference in the length of the rails, even for the curves corresponding to the coning, because the axle usually does not maintain a radial position on the curve, especially when grouped with others in a frame or truck; the coning, therefore, may be neglected as an element in the problem. The slipping of the wheel longitudinally on the rail results in a force being developed in the direction of the rail length (pull or push) which adds to the tractive pull required and produces wear of rail and wheel. It does not, however, cause bending stresses in the rail and, therefore, need not here be taken into account, except as it may affect the way in which lateral slip on the rail occurs in combination with it and also as it may influence the magnitude of the lateral force, which is one component of the force required to produce the resulting slip on the rail.

b.—Changing the Direction of the Locomotive in Passing Around the Curve

If in traversing a curve the axles of each pair of wheels took a radial direction (normal to the curve), the principal force required to change the direction of the motion of the truck or frame would be equal to that commonly called the centrifugal force; the centrifugal force and the transverse inclination of the track cause a lateral reaction against the rail. For a radial position of the axle, the force producing lateral bending in the rail would then be the resultant of the centrifugal force and the component of the load due to the transverse inclination of the track.

When several axles are connected to a single stiff frame, as in a locomotive, quite different conditions are set up. The axles of the drivers must remain

* "The Economic Theory of Railway Location", p. 285.

parallel to each other. The tendency of the whole group of drivers to go straight ahead must be overcome by a lateral force exerted by the outer rail against the flanges of one or more of the wheels at the front of the frame. In the case of the locomotive, this turning movement is effected at the outer front driver, or at the outer wheels of the front truck, or by a combination of these truck wheels and the first driver. What wheel or combination of wheels will participate in this turning action may be expected to depend on the curvature of the track, the design of the locomotive, and the stiffness and play of the front truck connection with the locomotive frame, and, also, in some cases, on the flexibility of the connections of the front pair of drivers with the other drivers of the locomotive. The action of these forward outer wheels therefore is to press against the outer rail, the outward lateral force thus exerted tending to increase the curvature of the outer rail; in some cases, by reason of friction on the rail, the truck wheel on the inner rail may exert a lateral pull in the same direction on that rail. As a result of this turning action, the front drivers (both inner and outer) will be made to slip laterally on the rail; that is, inwardly radially to the curve. Further back along the frame of the locomotive will be a point which will act as a center of rotation and about which the turning of the locomotive will take place. If the lateral slip at any wheel is inward with reference to the curve (that is, toward the center of the curve), the effect on the rail is that of a lateral force acting inwardly of the curve, thus putting an inward lateral pressure on the inner rail and even on the outer rail, since the force may be transmitted by a wheel to the rail by friction at the top of the rail. The foregoing statement does not apply, of course, to those outer wheels the flanges of which are active in causing the locomotive to change direction; for these the pressure against the rail is outward, tending to increase the curvature of the rail.

The lateral slip of the drivers in front of the point about which rotation takes place will be inward with reference to the curve; that of the drivers back of the point will be outward. It is apparent that the position of this center of rotation will depend on the number of wheels in the frame, the position the wheels take with respect to the two rails, and the direction of the resultant slip of the wheels. If, as may happen, the axle of the next to the last pair of drivers remains normal to the curve, the center of rotation will be on the inner rail at this driver, provided, as is probable, that all the longitudinal slip of the drivers of this axle is taken by the outer driver. It seems probable that the center of rotation in some cases may be somewhat ahead of the next to the last driver. It is true, of course, that the several drivers on one side may not lie exactly in a straight line; the lateral play of the journals will allow side movement, the amount depending on the amount of the wear at the time. Fig. 38 represents the position of the wheels and the direction of a part of the lateral forces exerted by the rails on the wheels of the Mikado type locomotive at low speeds under conditions similar to those named. It is seen that the point of rotation is at or close to the third driver axle. The greatest lateral slip for any driver may be expected to occur under the front drivers. The

lateral slip of the several drivers will then be proportional to the distance along the inner rail from the point of rotation to the inner driver of a given pair.

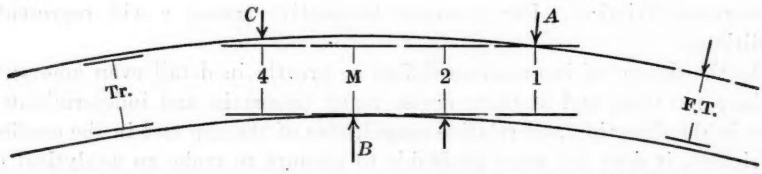


FIG. 38.—POSITION OF THE WHEELS OF A MIKADO TYPE LOCOMOTIVE WHEN TRAVERSING A CURVE AT LOW SPEEDS.

Generally, the two-wheel front truck is connected to a radius bar, a swinging arm that is pivoted at a point back of the truck, and a limit of rotation is provided, so that after this limit is reached the flange of the outer wheels will press against the outer rail and thus aid in the turning action. To what extent the axles of the front truck will approximate a radial condition on the curve and thus will have minimum lateral slip will depend on the manner of the attachment and the sharpness of the curve. The trailing wheels are also pivoted on a swinging arm so that the axle possibly may take a radial position. When the limit of the swing of this arm is reached, these wheels also contribute to the stiffness of the frame and must be slid outwardly; thus an outward lateral force on the rails is developed at the trailers.

In Figs. 73 and 74 of Article 15, "Lateral Bending of Rail on Curves", the position taken by the drivers and other wheels on curved track is shown for several locomotives. A study of these diagrams and of the amount and direction of the bending of the rails will indicate the position of the center of rotation of the locomotive. The relative amounts of the lateral slip at the several wheels may also be found rather closely.

It should be noted further that as both longitudinal and lateral slip on the rail will usually occur at the same time, resulting in slip in a diagonal direction, the force producing this slip of wheel in the diagonal direction (its magnitude being the force necessary to overcome friction) may be resolved into components along the rail and across the rail. In Fig. 39, the diagonal

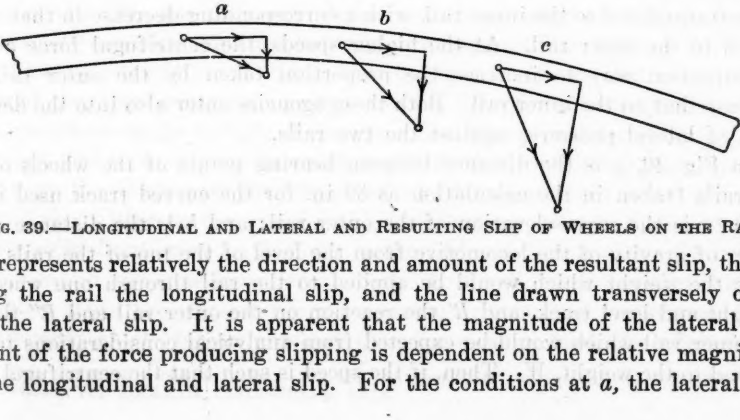


FIG. 39.—LONGITUDINAL AND LATERAL AND RESULTING SLIP OF WHEELS ON THE RAIL.

line represents relatively the direction and amount of the resultant slip, the line along the rail the longitudinal slip, and the line drawn transversely of the rail the lateral slip. It is apparent that the magnitude of the lateral component of the force producing slipping is dependent on the relative magnitudes of the longitudinal and lateral slip. For the conditions at *a*, the lateral com-

ponent or lateral pressure against the rail will be small. For equal slip in the two directions, as at *b*, which may be the condition for a short truck like a four-wheel car truck, the lateral component will be 0.7 of the force required to overcome friction. For a longer locomotive frame, *c* will represent the conditions.

As the design of locomotives differs so greatly in detail even among those of the same type, and as there are so many uncertain and indeterminate features in the direction and relative magnitudes of the slip and in the coefficients of friction, it does not seem profitable to attempt to make an analytical treatment of the lateral forces developed at the several wheels by the turning of the locomotive, although it would be easy to show that the magnitude of the lateral forces developed is necessarily considerable. Instead, it seems better to consider the data of the stresses observed in the rails themselves and to discuss these data in the light of the action herein outlined. It may be added that analytical considerations indicate that, for the same super-elevation and at low speeds, the degree of curve has little effect on the nature and magnitude of the turning forces beyond a lower limit of curvature where the assumed condition comes into action and within an upper limit where other elements may exert a controlling influence.

It should be pointed out that these turning forces, together with the centrifugal force and the component due to the transverse inclination of the track and the forces required to produce lateral slip, and including the reacting force at the inner rail, are the principal and most important lateral forces producing bending moment and bending stress in the two rails of curved track.

c.—Division of Load by Reason of Transverse Inclination of Track and Centrifugal Force

On straight track having the rails at the same level transversely, it may be presumed that the load on one axle is transmitted in equal amounts to the two rails. On curves an equal division between the two rails may not be generally expected. At low speeds (the centrifugal force being negligible), the super-elevation of the outer rail results in more than one-half the load being transmitted to the inner rail, with a corresponding decrease in that transmitted to the outer rail. At the higher speeds, the centrifugal force acts in an important way to increase the proportion taken by the outer rail and decrease that on the inner rail. Both these agencies enter also into the development of lateral pressures against the two rails.

In Fig. 40, g is the distance between bearing points of the wheels on the two rails (taken in the calculation as 59 in. for the curved track used in the tests); e is the super-elevation of the outer rail; and h is the distance of the center of gravity of the locomotive from the level of the top of the rails. Use W as the weight which would be applied to the rail through one wheel for straight and level track, and R' the reaction on the outer rail and R'' that on the inner rail which would be expected from analytical considerations to correspond to the weight, W. Then, if the speed is such that the centrifugal force

is negligible, it may be shown that the load transmitted to the outer rail will be given approximately by the following equation, the cosine of the angle of the transverse inclination of the track being taken as unity,

$$R' = W\left(1 - 2\,\frac{h}{g}\,\frac{e}{g}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (29)^*$$

and that transmitted to the inner rail,

$$R'' = W\left(1 + 2\,\frac{h}{g}\,\frac{e}{g}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (30)$$

For $h = 72$ in. and $e = 6$ in., Equations (29) and (30) indicate that for low speeds the load transmitted to the outer rail is 25% less than that on track level transversely and that to the inner rail is 25% greater than the normal load. It is evident that the inequalities in the division of load between the two rails may be a matter of some consequence.

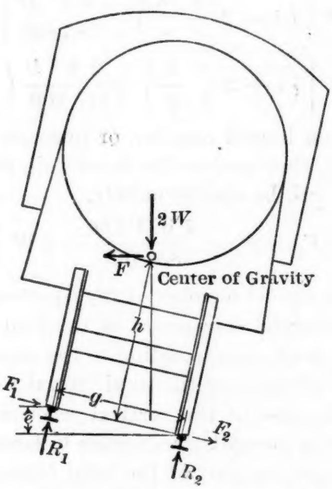


FIG. 40.—FORCES AND REACTIONS ON CURVED TRACK HAVING TRANSVERSE INCLINATION.

Equations (29) and (30) were derived on the assumption that the body of the locomotive retains the same position with respect to the axles of the drivers that it has on straight track. If, as may be the case, the greater weight on the inside of the curve causes the springs on that side of the locomotive to deflect more, and those on the outside of the curve less, than would normally be found, the result will be to tilt the locomotive still further and thus to throw greater weight on the inner rail than is given by Equations (29) and (30). The effect of this tilting on the transfer of load is less accordingly than that due to transverse inclination of track alone, as the tilting action is about the point of attachment of the equalizing levers to the frame of the locomotive, which is somewhat above the level of the axles of the drivers. As the springs deflect less proportionately for an overload than for a small load, the effect of this

* This equation number follows the last number used in the second progress report, *Transactions*, Vol. LXXXIII (1919–20), p. 1574.

change in deflection of the springs will not be as great as would otherwise be expected. It, however, may need some consideration.

For the higher speeds, the centrifugal force tends to counteract this inequality. For the speed corresponding to the super-elevation given to the track, the inequality vanishes, and it would be expected that the rails will receive equal loads. For still greater speeds, the outer rail will receive the greater load. In any case, the load on a rail would be expected to be the algebraic sum of that due to Equation (29) or Equation (30) and that due to the centrifugal force. The centrifugal force at V miles an hour on a $D°$ curve due to the weight, $2\,W$, is, approximately, $F = \frac{2\,W\,V^2\,D}{85\,800}$. Consider this force to be applied at the center of gravity of the locomotive. The reaction of the outer and inner rails, respectively, will then be:

$$R_1 = W\left[\left(1 - 2\,\frac{e}{g}\,\frac{h}{g}\right) + \frac{2\,V\,D}{85\,800}\left(\frac{h}{g} + \frac{1}{2}\,\frac{e}{g}\right)\right] \ldots\ldots (31)$$

$$R_2 = W\left[\left(1 + 2\,\frac{e}{g}\,\frac{h}{g}\right) - \frac{2\,V^2\,D}{85\,800}\left(\frac{h}{g} - \frac{1}{2}\,\frac{e}{g}\right)\right] \ldots\ldots (32)$$

If F_1 is the resulting lateral reaction or pressure against the outer rail of the curved track and F_2 that against the inner rail, the sum of the lateral reactions for the two rails will be approximately,

$$F_1 + F_2 = \frac{2\,W\,V^2\,D}{85\,800} - 2\,W\,\frac{e}{g} \ldots\ldots\ldots\ldots (33)$$

The first term of the second member of the equations is the centrifugal force and the second the horizontal component of the load due to super-elevation of the outer rail. At the speed corresponding to the super-elevation, $F_1 + F_2 = 0$. It is apparent that the division of the total lateral force between F_1 and F_2 is indeterminate, as in the case of the vertical reactions of the two hinges of a door. Generally, a low or a smaller resistance to lateral slip on one wheel may be expected to cause a greater part of the total lateral force to go to the other rail, except as modified by the bearing of the flange of the wheel against the side of the rail. It will be seen from Equation (33) that the value of $F_1 + F_2$ for the highest super-elevation of the track used in the tests, $8\frac{1}{2}$ in., is 14% of the total load on the axle.

Values of the ratio of the vertical load on the outer and inner rail of curved track to the corresponding value on straight track, as found by Equations (31) and (32), are given in Tables 21 and 22 for the curves and speeds used in the tests.

d.—Spreading Action of Drivers and Other Wheels

The stiffness of the frame and the smallness of the lateral play in the journals when the locomotive is just out of the shops may leave little individual freedom of lateral movement in the drivers. With a long and rigid wheel base, it may be thought that on sharp curves a flange of an intermediate driver will be crowded against the inner rail while the flanges of the end drivers are pressed against the outer rail, and, thus, that there would be a marked tendency

to spread the rails apart, this action creating lateral bending forces against the two rails. As the gauge of the wheels is less than that of the track (the difference ranging from ¾ in. to 1 in. for new wheels and sometimes as much as 2 in. for badly worn flanges and widened gauge), and as on curves there may be an increase in gauge over the standard, and as there may be some flexibility in the frame and bearings, it is to be expected that, for a given wheel-base and other stated conditions, the limiting degree of curve below which no spreading action exists of the kind here meant, will be rather large. For the purpose of giving greater freedom, the flange is sometimes omitted from one or more drivers, making so-called blind drivers.*

TABLE 21.—RATIO OF LOADS ON INNER AND OUTER RAIL, ATCHISON, TOPEKA AND SANTA FE RAILWAY.

Locomotive.	Degree of curve.	Super-elevation, in inches.	Speed, in miles per hour.	Ratios. Analytical Values. Inner rail.	Ratios. Analytical Values. Outer rail.	Ratios. Test Values. Inner rail.		Ratios. Test Values. Outer rail.	
RIBERA:									
Mountain, No. 3710	6°	4.7	5	1.20	0.80	1.22		0.78	
			25	1.09	0.91	1.16		0.84	
			35	1.00	1.00	1.02		0.98	
			50	0.77	1.26	0.81		1.19	
Santa Fe No. 3813	6°	4.7	5	1.20	0.80	1.19		0.81	
			25	1.09	0.91	1.11		0.89	
			40	0.92	1.09	1.01		0.99	
Mountain, No. 3710	10°	4.7	5	1.19	0.81	1.21		0.79	
			25	1.02	0.99	0.99		1.01	
			35	0.85	1.17	0.81		1.19	
Santa Fe, No. 3813	10°	4.7	5	1.19	0.81	1.20		0.80	
			25	1.02	0.99	1.00		1.00	
			35	0.85	1.17	0.83		1.17	
Santa Fe, No. 3829	10°	4.7	5	1.19	0.81	1.28		0.72	
			25	1.02	0.99	1.00		1.00	
			35	0.85	1.17	0.88		1.12	
						Up Grade.	Down Grade.	Up Grade.	Down Grade.
BEALVILLE:									
Santa Fe, No. 3832	10°	4.4	10	1.16	0.84	1.15	1.15	0.85	0.85
			18	1.10	0.91	1.09	1.08	0.91	0.92
Santa Fe, No. 3653	10°	4.4	10	1.16	0.84	1.18	1.18	0.82	0.82
			18	1.10	0.91	1.13	1.12	0.87	0.88
CAJON:									
Santa Fe. No. 3832, fourth driver cylindrical	10°	5.4	10	1.20	0.80	1.27	1.36	0.73	0.64
			18	1.14	0.86	1.17	1.30	0.83	0.70
Santa Fe. No. 3832, fourth driver grooved	10°	5.4	10	1.20	0.80	1.32	1.32	0.68	0.68
			18	1.14	0.86	1.18	1.24	0.82	0.76

To find whether a given curve is below the limiting value for a given wheel-base on the basis that the flanges bear against the two rails in the manner outlined, the ordinates for the curve may be found. In Fig. 41, the flanges of the outer end drivers are both considered to bear against the outer rail at

* For a discussion bearing on the widening of gauge on curves, see Report of Committee V on Track, *Proceedings*, Am. Ry. Eng. Assoc., Vol. 23, p. 575.

points which may be somewhat beyond the limits of the wheel-base, and the flanges of intermediate wheels against the inner rail. The ordinates, a and b, are then found. Then, if g is the gauge of the track and g' the gauge of the wheels, the distance, $a—b$, must be enough greater than $g—g'$ to give reasonable clearance. For five drivers on a side, the term, b, vanishes if the middle driver is flanged; with a blind driver at the middle, the chord from the second to the fourth driver will be used in obtaining a value of b.

TABLE 22.—RATIO OF LOADS ON INNER AND OUTER RAIL, DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

Locomotive.	Degree of curve.	Super-elevation, in inches.	Speed, in miles per hour.	Ratios.			
				Analytical Values.		Test Values.	
				Inner rail.	Outer rail.	Inner rail.	Outer rail.
Mikado No. 1220.	4°	3.7	5 25 35 45	1.16 1.08 1.01 0.92	0.84 0.92 0.99 1.08	1.03 1.01 0.97 0.89	0.97 0.99 1.03 1.11
Pacific No. 1131..	4°	3.7	5 25 40 60	1.16 1.08 0.97 0.74	0.84 0.92 1.03 1.28	1.11 1.04 0.94 1.00	0.89 0.96 1.06 1.00
Mikado No. 1220.	6°	8.5	5 25 35 45	1.36 1.26 1.16 1.02	0.64 0.75 0.86 1.01	1.37 1.30 1.20 1.16	0.63 0.70 0.80 0.84
Mikado No. 1220.	7½°	6.4	5 25 35 45	1.27 1.14 1.01 0.84	0.73 0.87 1.00 1.19	1.29 1.19 1.10 0.97	0.71 0.81 0.90 1.03
Pacific No. 1131..	7½°	6.4	5 25 40 50	1.27 1.14 0.93 0.74	0.73 0.87 1.09 1.30	1.26 1.16 0.96 0.87	0.74 0.84 1.04 1.13

The assumption that the outer rear driver bears against the outer rail is not warranted by the observations and tests made on curved track; the rear driver generally keeps well away from the outer rail at low speeds and usually also at the higher speeds. This position of the rear driver in effect lengthens the wheel-base and decreases the degree of curve for which clearance would be found sufficient if other elements did not enter into the phenomenon. An important modification of the assumptions is that the lateral deflection of the rails at some of the wheels is found to be considerable, particularly in the

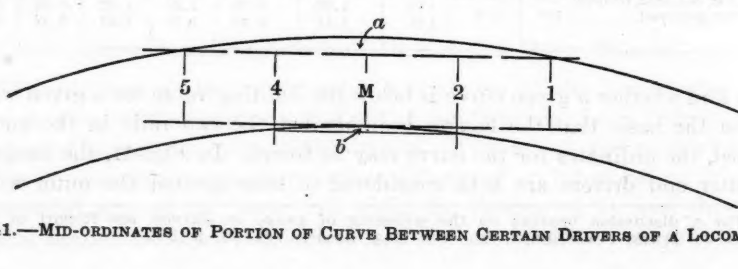


FIG. 41.—MID-ORDINATES OF PORTION OF CURVE BETWEEN CERTAIN DRIVERS OF A LOCOMOTIVE.

inner rail at a rear intermediate driver. With the Mountain type locomotive, on a 10° curve, the inner rail was found to deflect inwardly of the curve at the third driver as much as 0.5 in., the gauge of the track increasing to more than that extent because the outer rail also deflects somewhat. The Santa Fe type locomotive with all drivers flanged and the Santa Fe type with the main driver flangeless appeared to traverse the 10° curves without the flanges of the intermediate drivers bearing against the inner rail, and hence there was no spreading action of the nature of that usually considered when this subject is discussed. As a very heavy thrust against the inner rail on 10° and even on 6° curves is found—really an excessive pressure—it is plain that an explanation of its source other than the spreading action of the flanges must be sought.

The explanation that appears plausible is connected with the change of direction of the locomotive. Consider in Fig. 38 that the force changing the direction of the locomotive is applied by the rail to the flange of the outer first driver at A, or by the wheels of the front truck at some point ahead of this. Consider that the rotation is about the point, B, on the inner rail and that the rear outer driver is slipped outwardly at C. The lateral pressure at B will have to resist the forces at A and C, except as other wheels may assist. As the other wheels slip laterally, if the wheel at B does not slip, as seems to be the case, the main part of the resisting lateral thrust will be taken at B. This seems to be the more plausible, when, as is found in most tests at low speed, the load transmitted by the driver in question is greatly in excess of that taken by the others. It will be found also from some of the tests with the Santa Fe type locomotive that the conditions of this lateral thrust change materially when all ten drivers are flanged and when four of them are flangeless. Measurements of the lateral deflection of the inner and outer rails of curved track confirm the action of the lateral forces referred to previously and show a considerable increase in gauge without the flanges touching the inner rail.

Altogether, it seems to be evident that the limiting conditions of curves cannot be determined by a study of ordinates and clearances alone. The absence of wear on the gauge side of the inner rail of such curves of itself would seem to absolve the flanges of the drivers from spreading action on the inner rail. The presence of very great lateral pressures against the inner rail is quite evident in the tests. These pressures produce a widening of the gauge, something like a spreading action, but the origin of the pressure should be attributed to sources other than lack of clearance of flanges of the intermediate drivers. It seems clear that the lateral force is transmitted by the drivers to the inner rail by means of the friction between the tread of the driver and the head of the rail. The very high vertical pressures transmitted by one or more of the inner drivers and the greater value of static friction combine, in many cases, to make the point of contact of the rear intermediate driver on the inner rail the center of rotation of the change of direction of the locomotive. Thus this driver is kept from slipping laterally while, at the same time, the great lateral pressure on the inner rail developed at this driver causes the lateral deflection and spreading of the inner rail to be considerable, even on

track of moderate curvature. In general, it is evident that the method of calculating clearances indicated in Fig. 41 is not generally applicable.

e.—Other Sources of Lateral Pressure

When the locomotive is pulling a load around a curve, the tractive pull of the locomotive at the coupling with the tender will not be in the direction of the tangent to the curve at that point, in other words, there will be obliquity of traction. This obliquity of traction will produce a lateral force on the rear end of the locomotive itself, inwardly of the curve, a force that is the component of the tractive force in the direction of the radius of the curve. The approximate direction of the frame of the locomotive may be found by considering that the frame is tangent to the curve at the point of rotation of the turning movement of the locomotive around the curve, that has already been referred to. The point of rotation has been found to be at or near the next to the last inner driver. For the Santa Fe type locomotive, on a 10° curve, the angle of the direction of the locomotive with the tangent to the curve would then be not more than 2°, and probably less, and for the other locomotives and for lighter curves, the angle would be smaller still. It will be seen that under these conditions the lateral component of the tractive force may be expected to be small in comparison with the other loads and forces acting. The effect of this lateral component applied at the point of the coupling will be to tend to swing the rear end of the locomotive inwardly of the curve and the front end outwardly. The effect at the rear drivers will be to relieve the outward lateral thrust on the rail at that point if these drivers do not slip outwardly, and to increase the lateral force acting on the locomotive at that point if the rear drivers do slip outwardly. Both conditions would tend to increase the lateral inward thrust of the driver at the point of rotation and also the outward lateral thrust at the front driver or front truck wheel. From the small value of the angle of obliquity and the possible magnitude of the tractive force, it seems very probable that all the lateral thrusts due to obliquity of traction are small. Whether they actually have any serious bearing on the lateral bending of the rail may best be found from experiments. It may be added that Wellington in the discussion of the effect of obliquity of traction on train resistance came to the conclusion that the additional force required to pull the train due to this cause was too small to need consideration.

On straight track, there are ordinarily lateral movements of locomotives and cars, or so-called vibrations, which cause lateral bending stresses in the rail. These may be due to variations in the track, or to lateral motion of the locomotives and cars. The lateral bending stresses produced in this way may be of considerable magnitude, as has already been shown. On curved track, the lateral outward and inward movements may be expected to be less than those on straight track because of the action of the lateral component of the load due to the transverse inclination of the track and of the lateral forces developed in the turning of the locomotive. Even at the speed of super-elevation the lateral forces will be quite effective in keeping the wheels in a given position. It is true, of course, that if the curved track is not in well-kept con-

dition of line and super-elevation, the lateral movement may be much greater than on straight track, as when the locomotive and cars careen from side to side.

It should be understood that the discussion of the action of curved track here made is preliminary to the discussion of the results of the tests; no analytical treatment can have finality.

13.—General Results of Tests on Curved Track.—In so complicated a problem, it is not easy to present the data of the tests, interpret the meaning of the results, and distinguish between the effects of the various factors which together influence the action of the locomotive and track. It is to be expected then that there may be some repetition or duplication of statement in the discussion. Space will permit the presentation of only a part of the data, but representative parts have been selected and general average values are given in the tables and diagrams.

Figs. 42 to 63, inclusive, give the stresses at the inside edge and the outside edge of the base of the inner and the outer rail under the wheels of six locomotives at several speeds throughout the revolution of the driver in the tests on the Atchison, Topeka and Santa Fe Railway and the Delaware, Lackawanna and Western Railroad. The observations from which these averages were obtained, when plotted with respect to the revolution of the driver, were found to be somewhat more scattered than is the case with straight track, as is to be expected from the greater number of variable factors entering into the problem, but the body of the observed values lies in a belt that is frequently within 6 000 lb. per sq. in. of stress of the line of average stress although in some cases the range is much wider. This is true for diagrams representing mean stress, stress at inner edge, and stress at outer edge of base of rail. It is evident then that, as in the case of straight track, the line or curve of average stress may be taken to be representative of the values, with the understanding that values may frequently be expected greater and less than this line of average stress within the limits of the belt, with occasional values greater or less than these limits, and that the range of stress above and below the average line may be taken to be 4 000 to 12 000 lb. per sq. in. for the rail sections and loads used in the tests.

In Figs. 64 to 67, inclusive, are given the stresses at the inside edge and the outside edge of the base of the inner and the outer rail under the several wheels of three types of locomotives at the speeds used in the tests.

In making comparisons between tests, reference may be made to the properties of the rail sections given in Table 1 and the weights of the locomotives given in Figs. 1 to 3.

From an examination of the diagrams, it is evident that there are marked differences in stresses under the several drivers, that these differences vary greatly with speed, and that there are high lateral bending stresses in the rail under certain wheels.

14.—Stresses Due to Vertical Bending of the Rail.—The mean stress in the base of rail (the average of the stresses observed at the two edges and generally hereafter called the vertical bending stress), may be taken as represen-

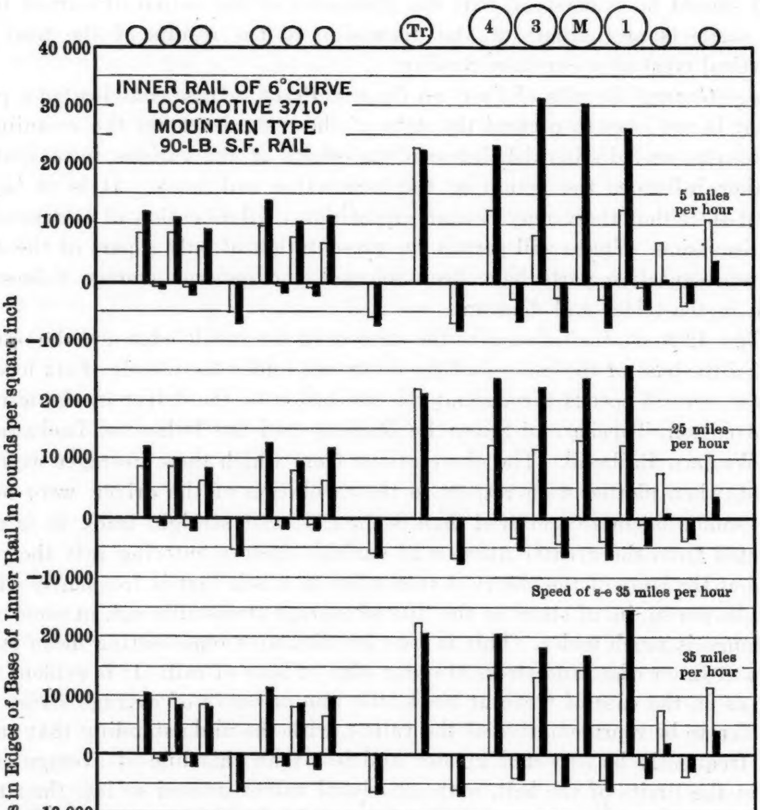


FIG. 42.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER RAIL OF THE 6° CURVE, SERIES 5319–5337, MOUNTAIN TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

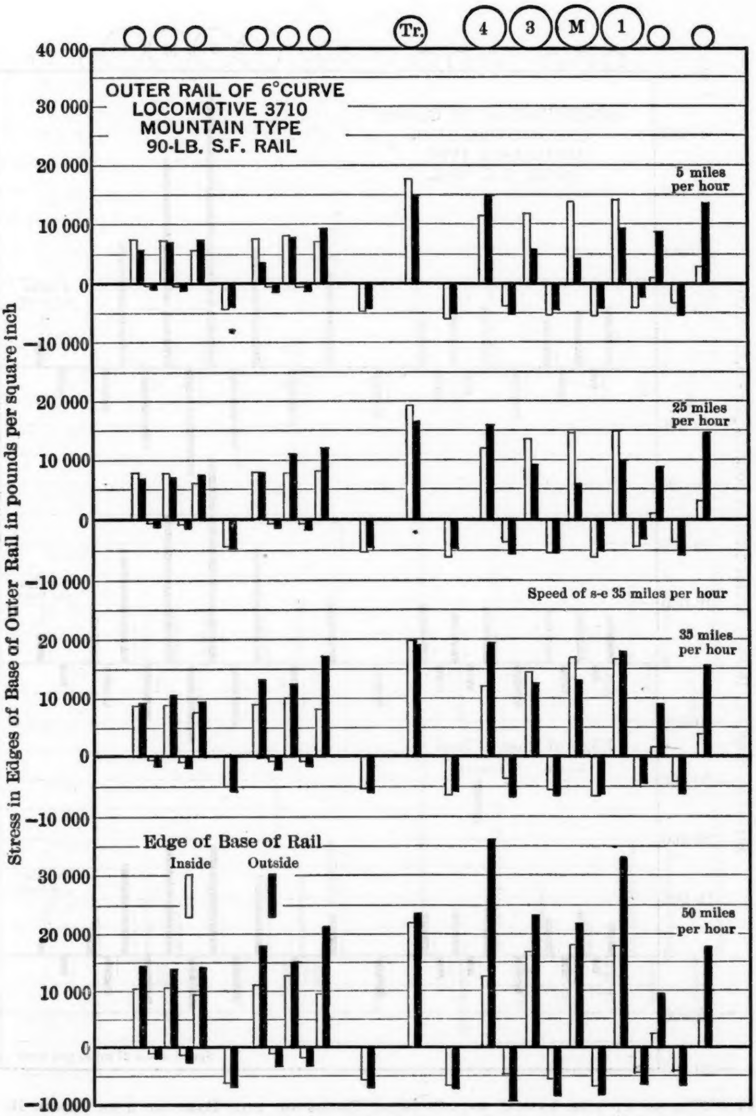


FIG. 43.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE OUTER RAIL OF THE 6° CURVE, SERIES 5319–5337, MOUNTAIN TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

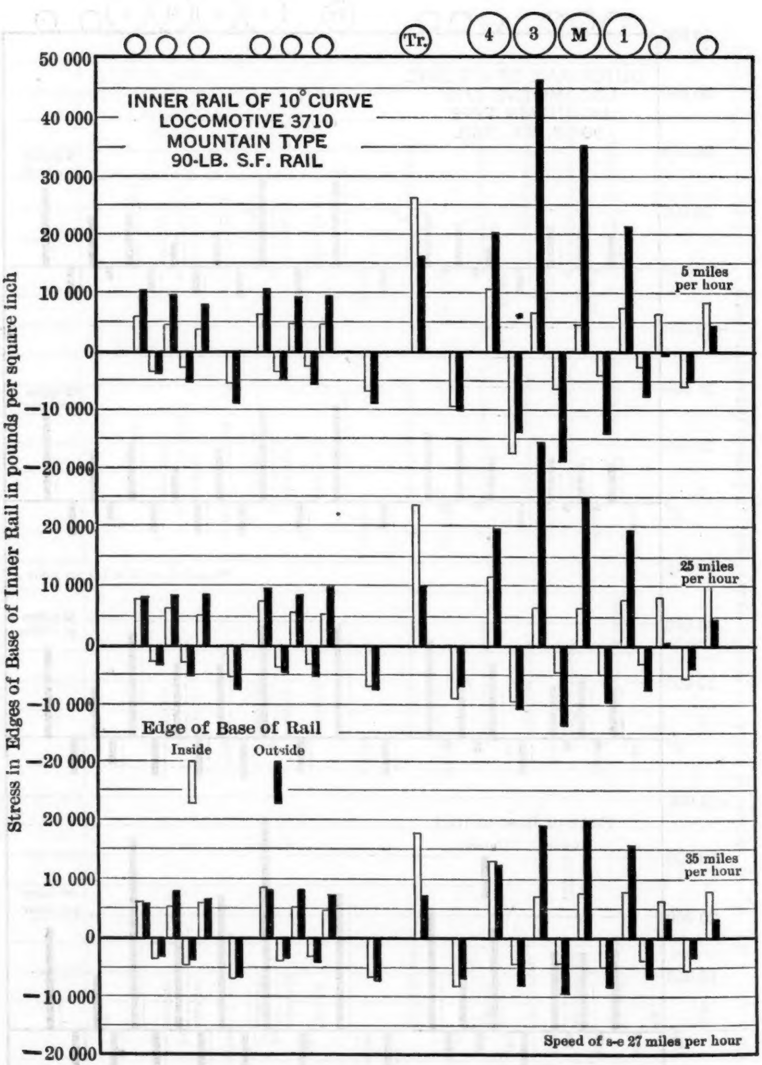


FIG. 44.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER RAIL OF THE 10° CURVE, SERIES 5351–5365, MOUNTAIN TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

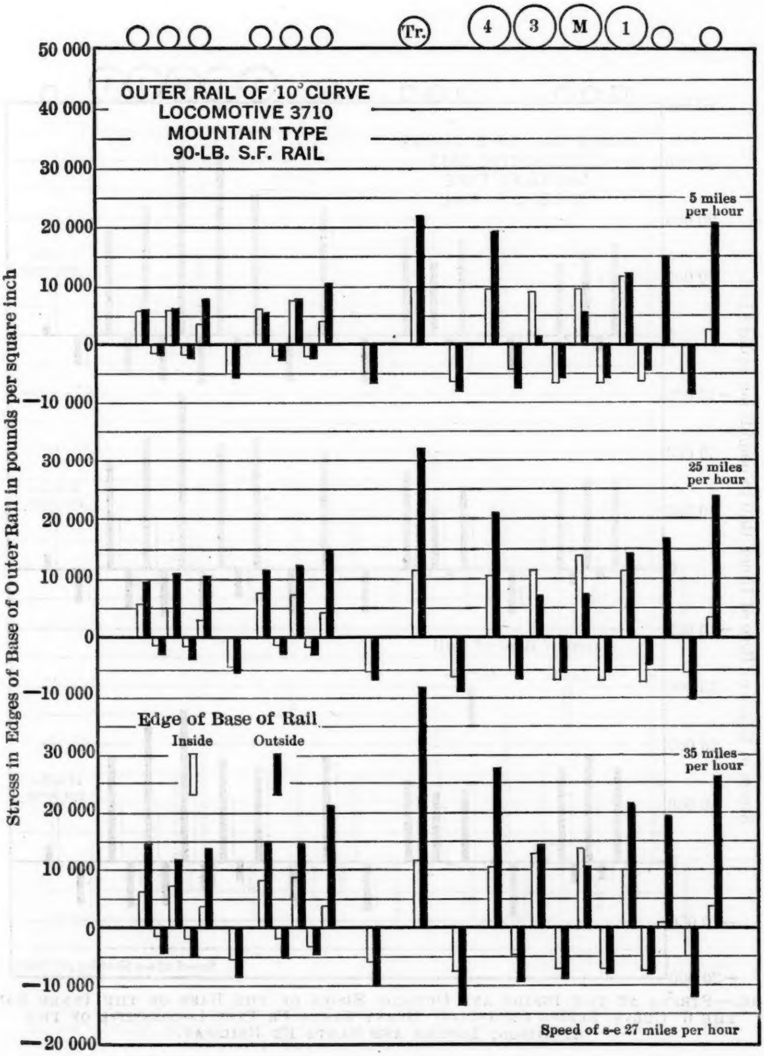


FIG. 45.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE OUTER RAIL OF THE 10° CURVE, SERIES 5351–5365, MOUNTAIN TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

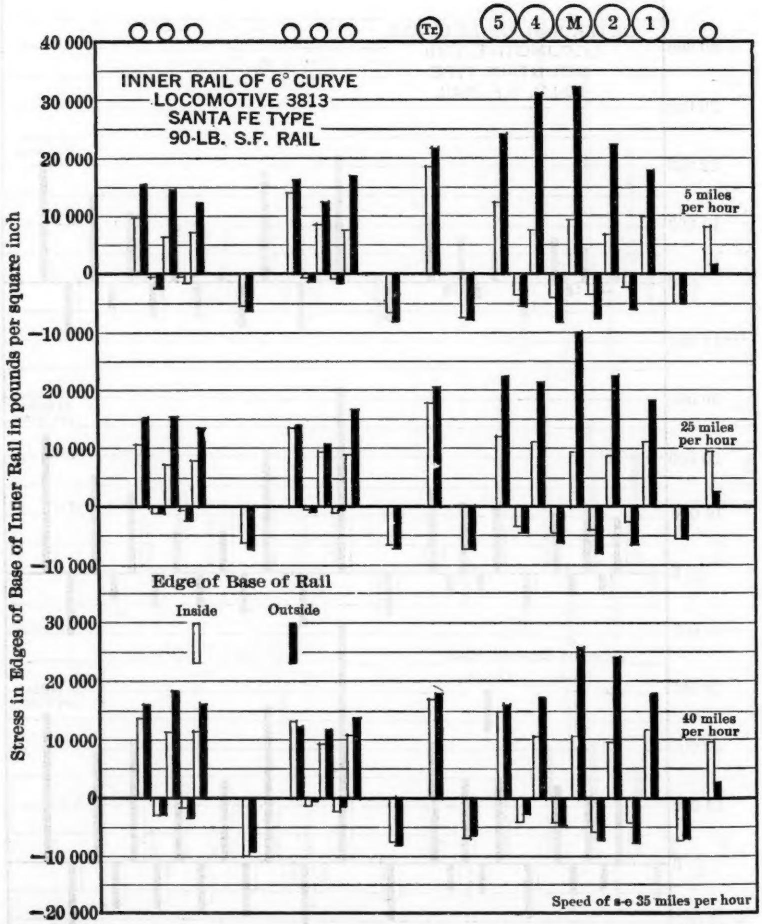


FIG. 46.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER RAIL OF THE 6° CURVE, SERIES 5383–5400 HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

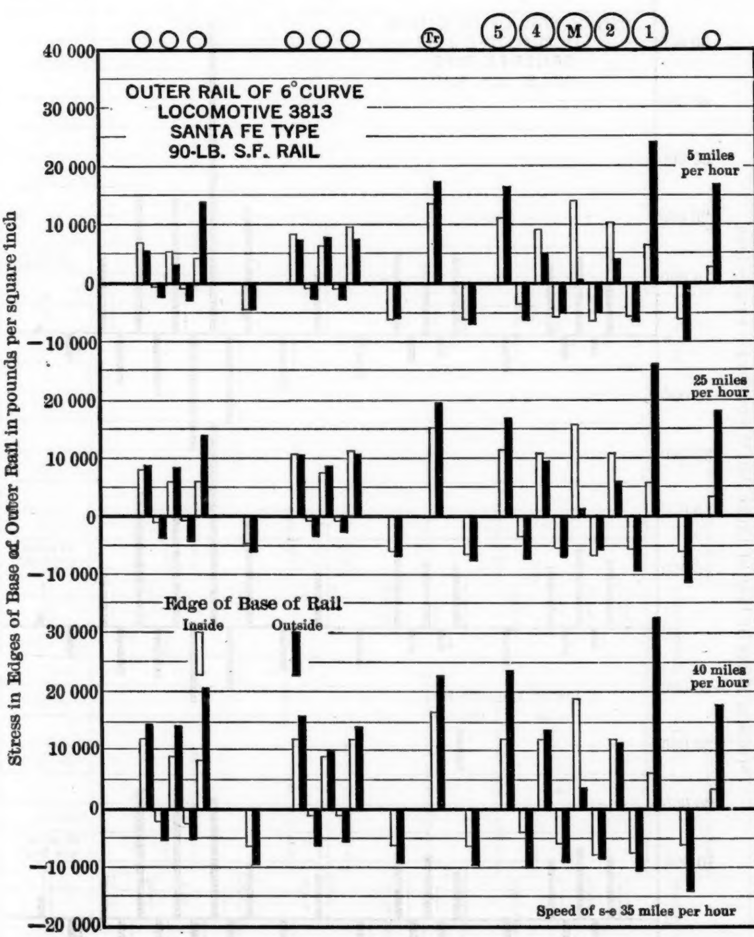


FIG. 47.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE OUTER RAIL OF THE 6° CURVE, SERIES 5383–5400, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

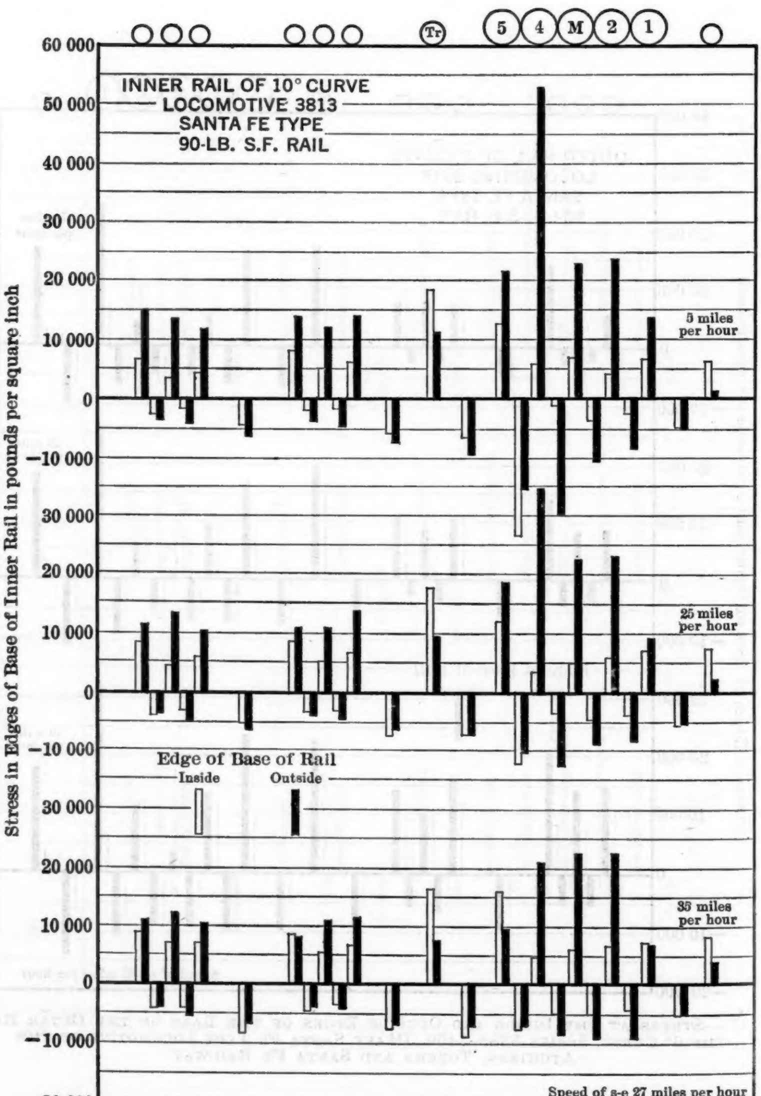


FIG. 48.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER RAIL OF THE 10° CURVE, SERIES 5366–5382, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

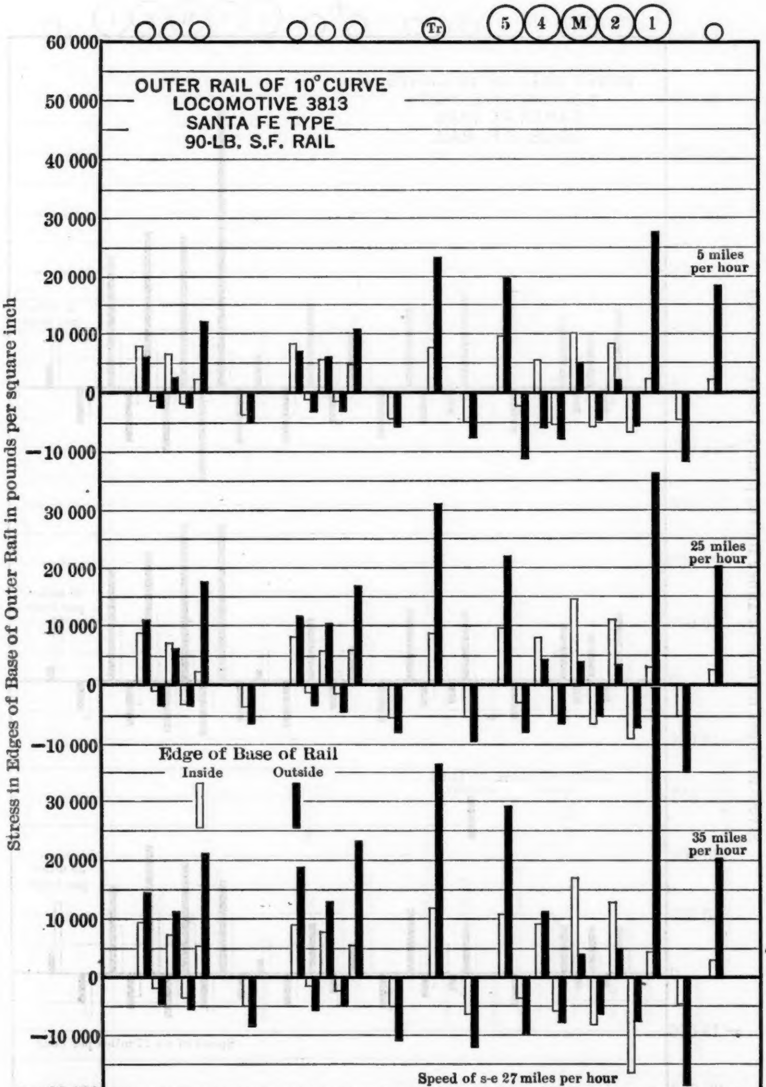


FIG. 49.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE OUTER RAIL OF THE 10° CURVE, SERIES 5366–5382, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

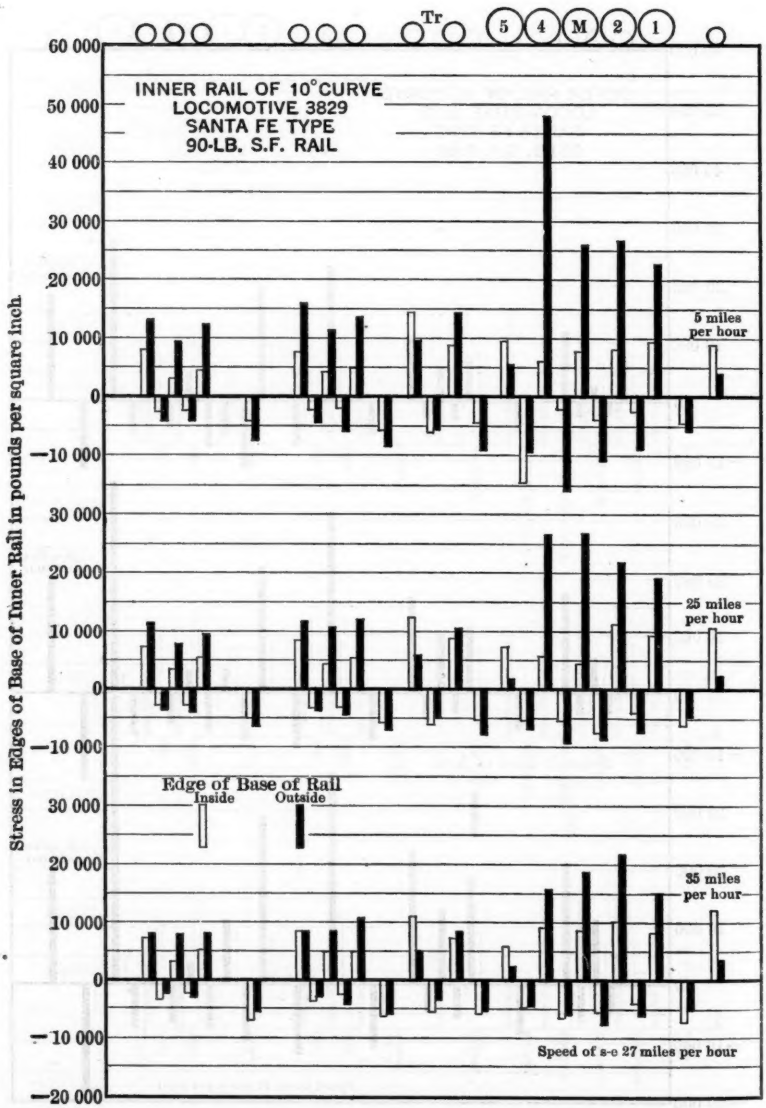


FIG. 50.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER RAIL OF THE 10° CURVE, SERIES 5425–5433, DOUBLE TRAILER HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

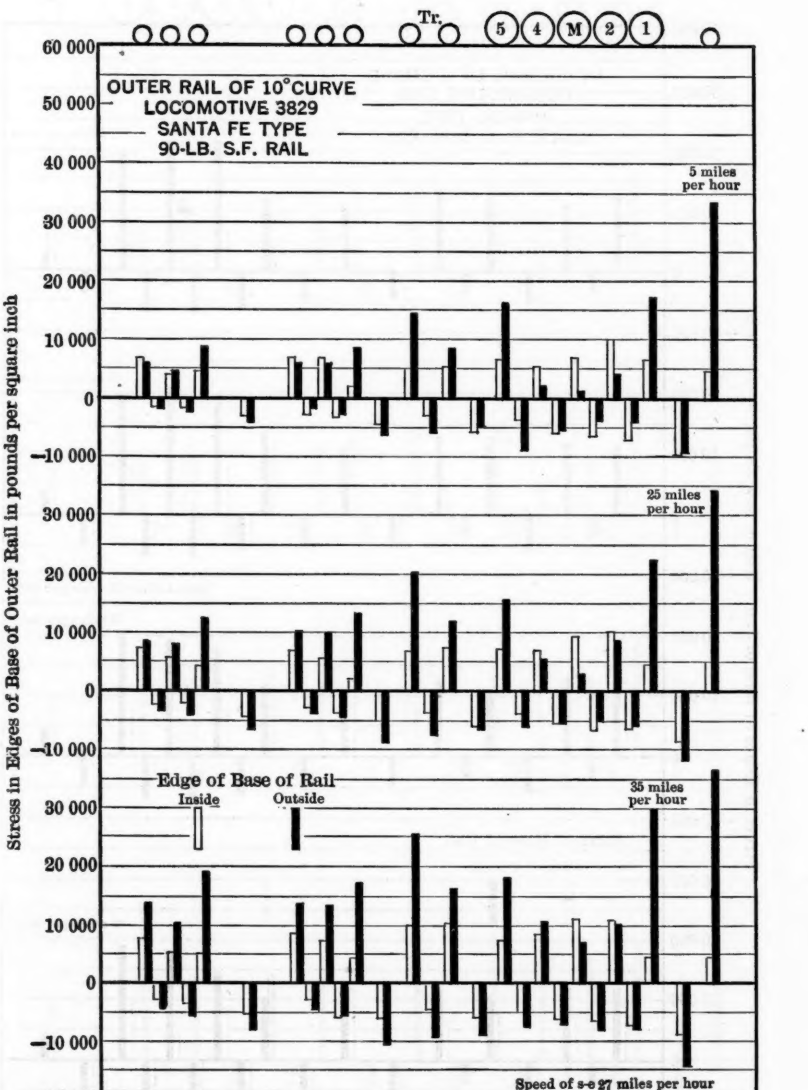


FIG. 51.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE OUTER RAIL OF THE 10° CURVE, SERIES 5425–5433, DOUBLE TRAILER HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

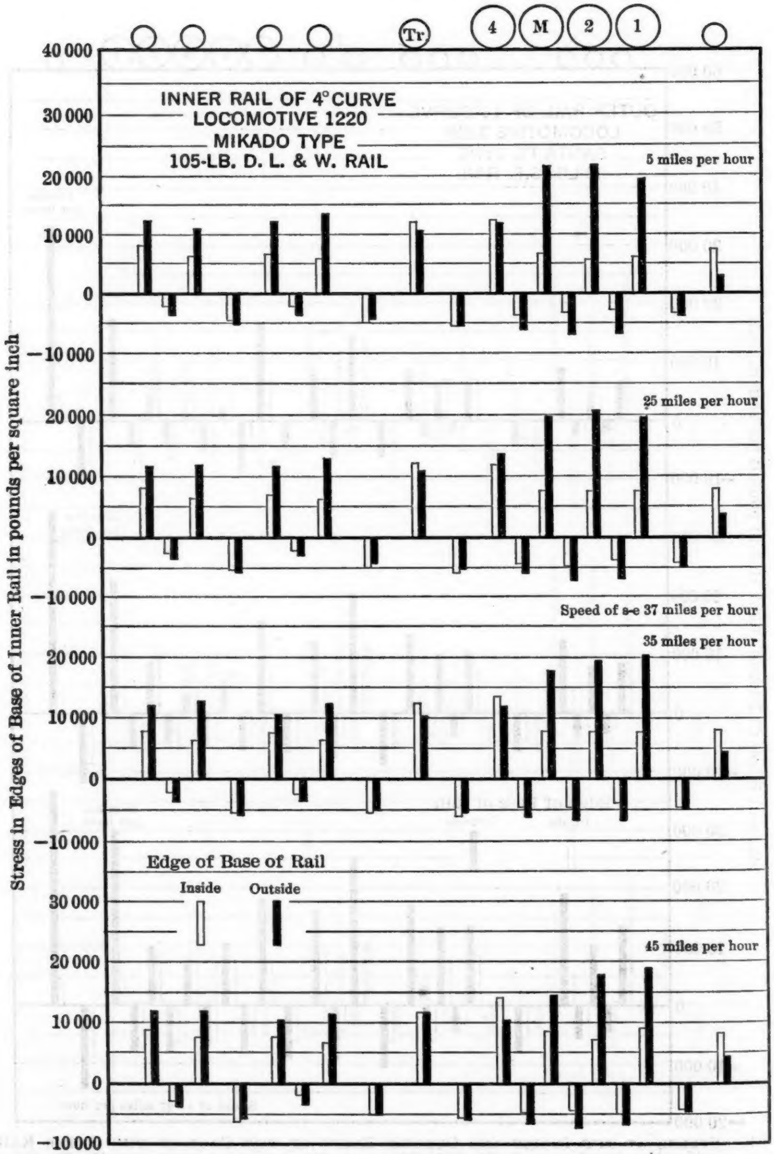


FIG. 52.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER RAIL OF THE 4° CURVE, SERIES 5150–5169, MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

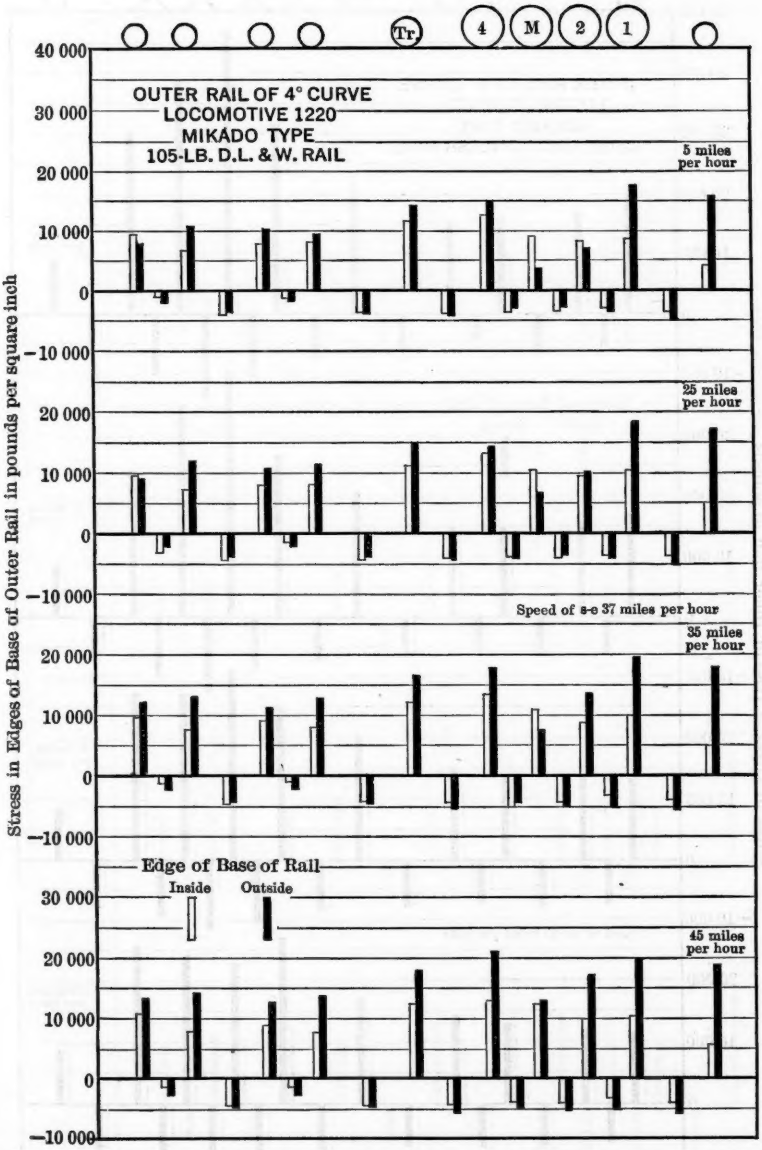


FIG. 53.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE OUTER RAIL OF THE 4° CURVE, SERIES 5150–5169, MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

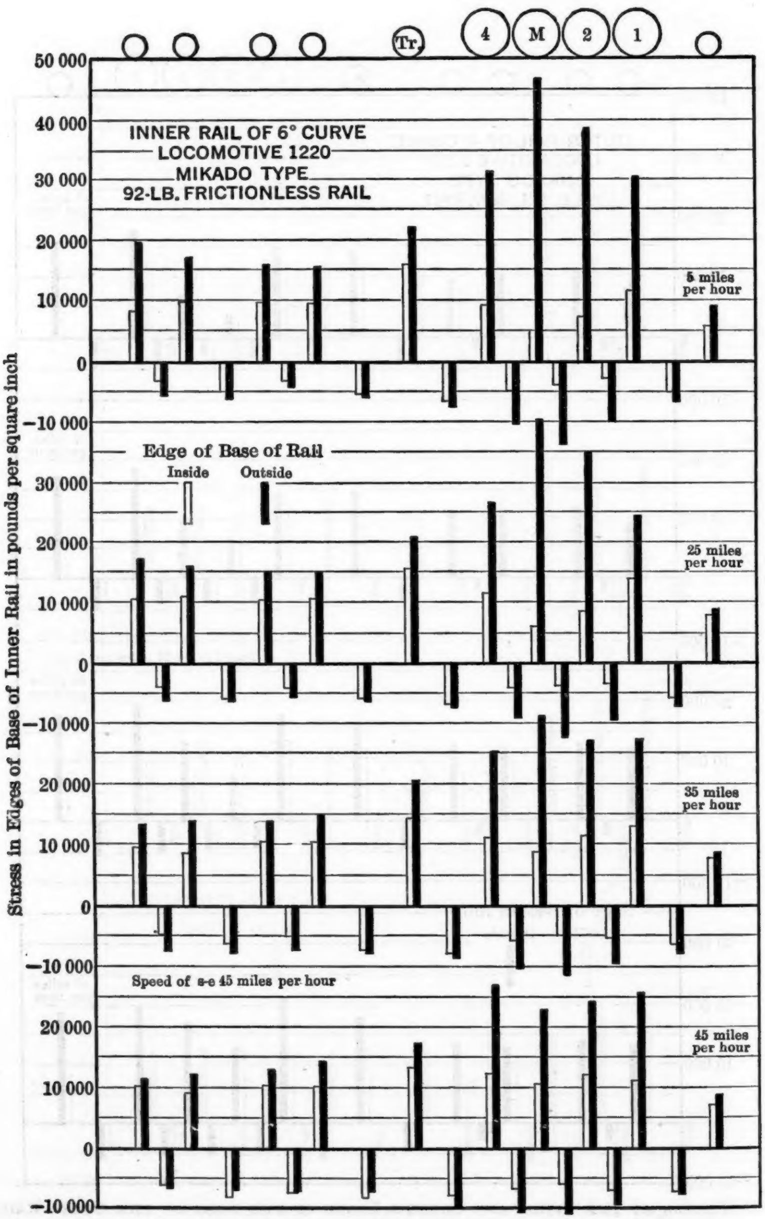


FIG. 54.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER RAIL OF THE 6° CURVE, SERIES 5191–5205, MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

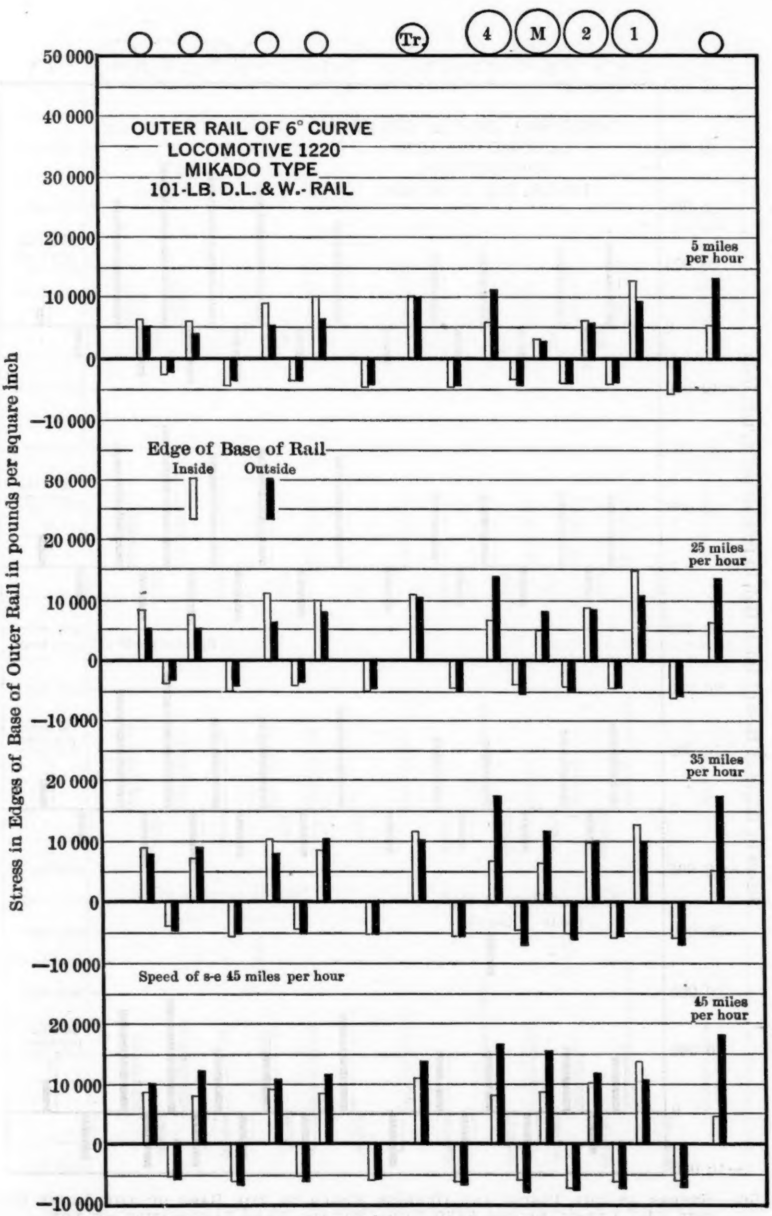


FIG. 55.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE OUTER RAIL OF THE 6° CURVE, SERIES 5191–5205, MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

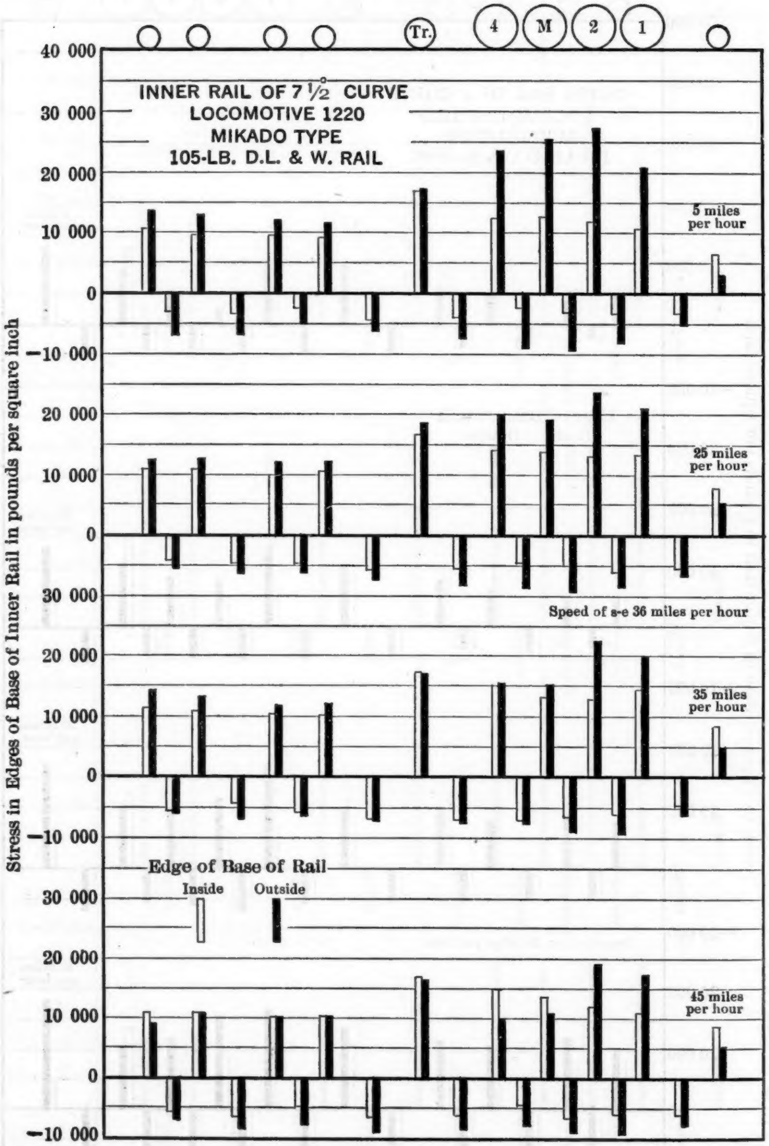


FIG. 56.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER RAIL OF THE 7½° CURVE, SERIES 5170–5190, MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

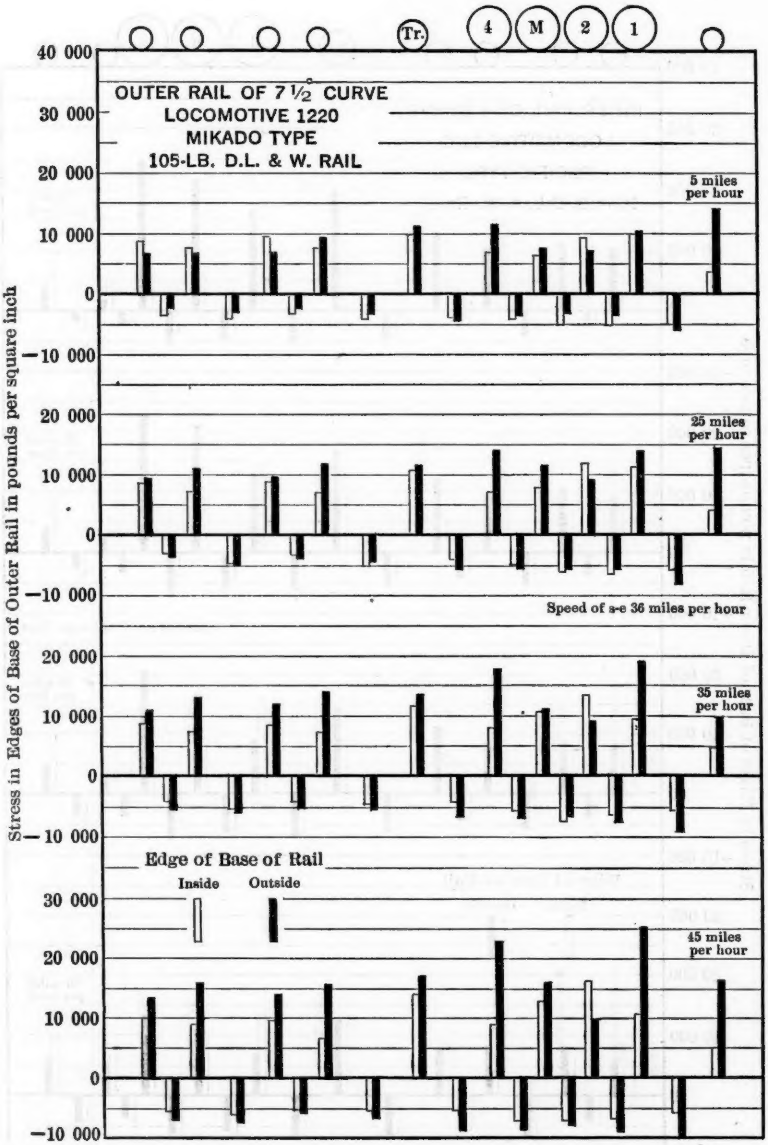


FIG. 57.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE OUTER RAIL OF THE 7½° CURVE, SERIES 5170–5190, MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

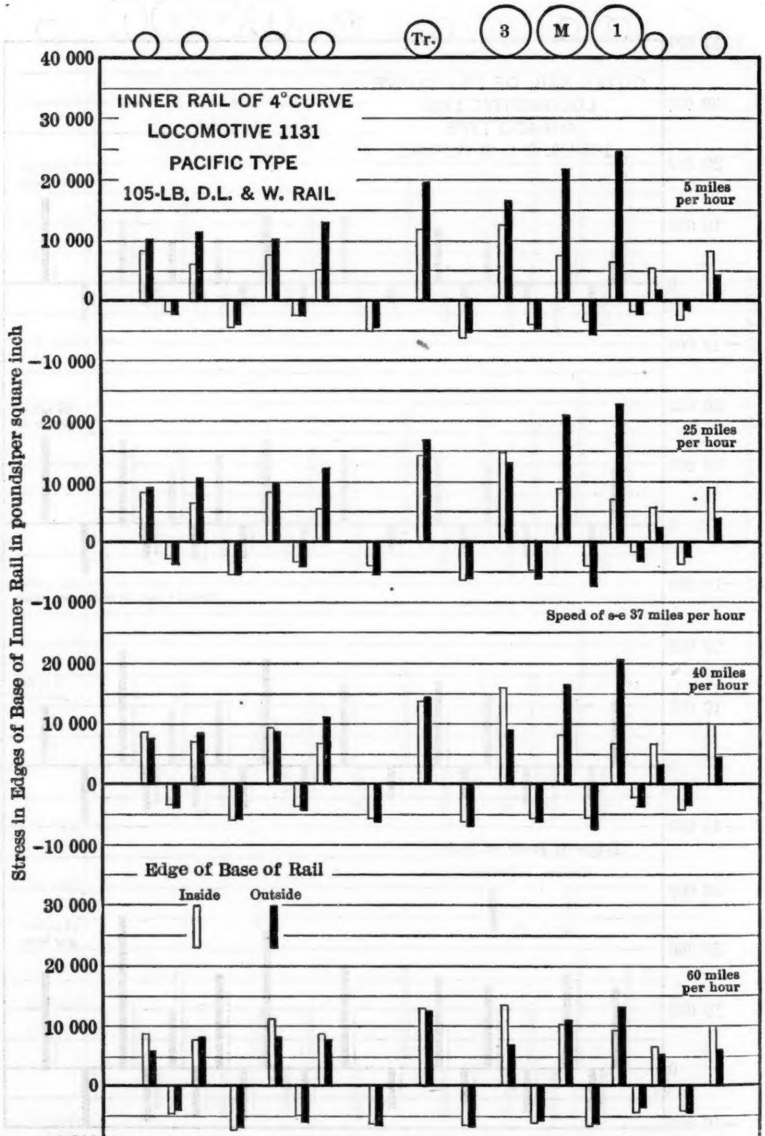


FIG. 58.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER RAIL OF THE 4° CURVE, SERIES 5100–5116, PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

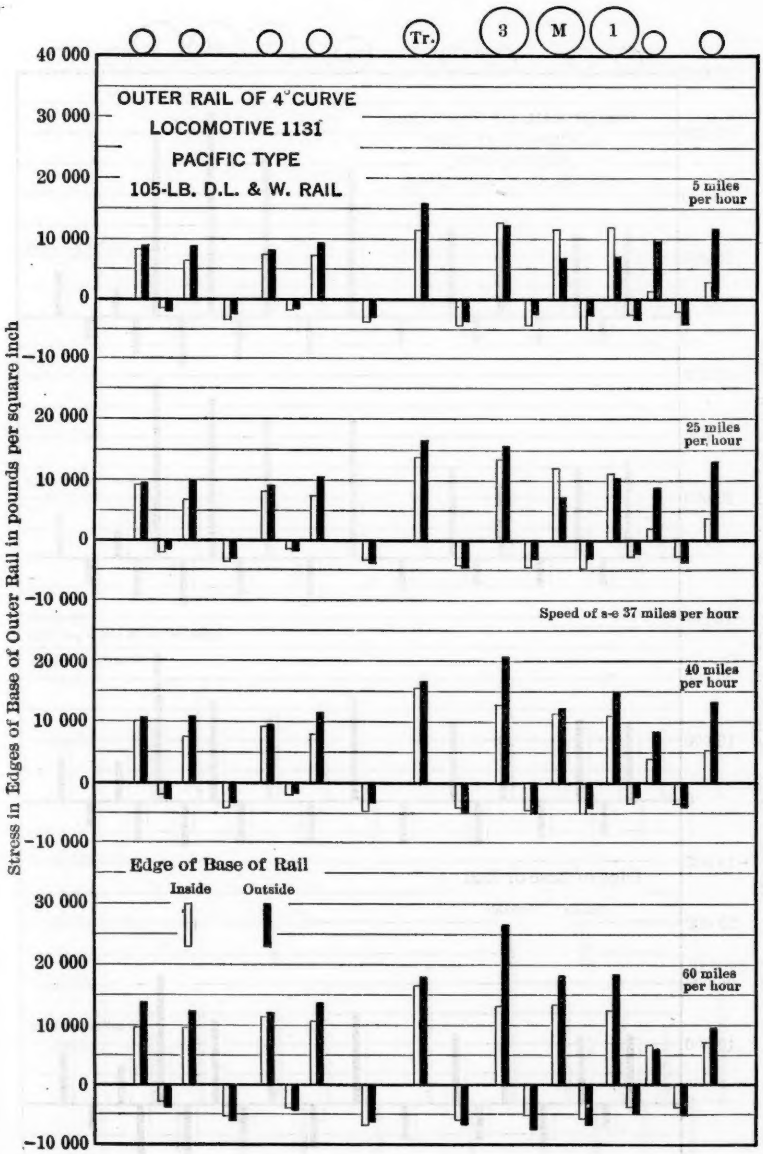


FIG. 59.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE OUTER RAIL OF THE 4° CURVE, SERIES 5100–5116, PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

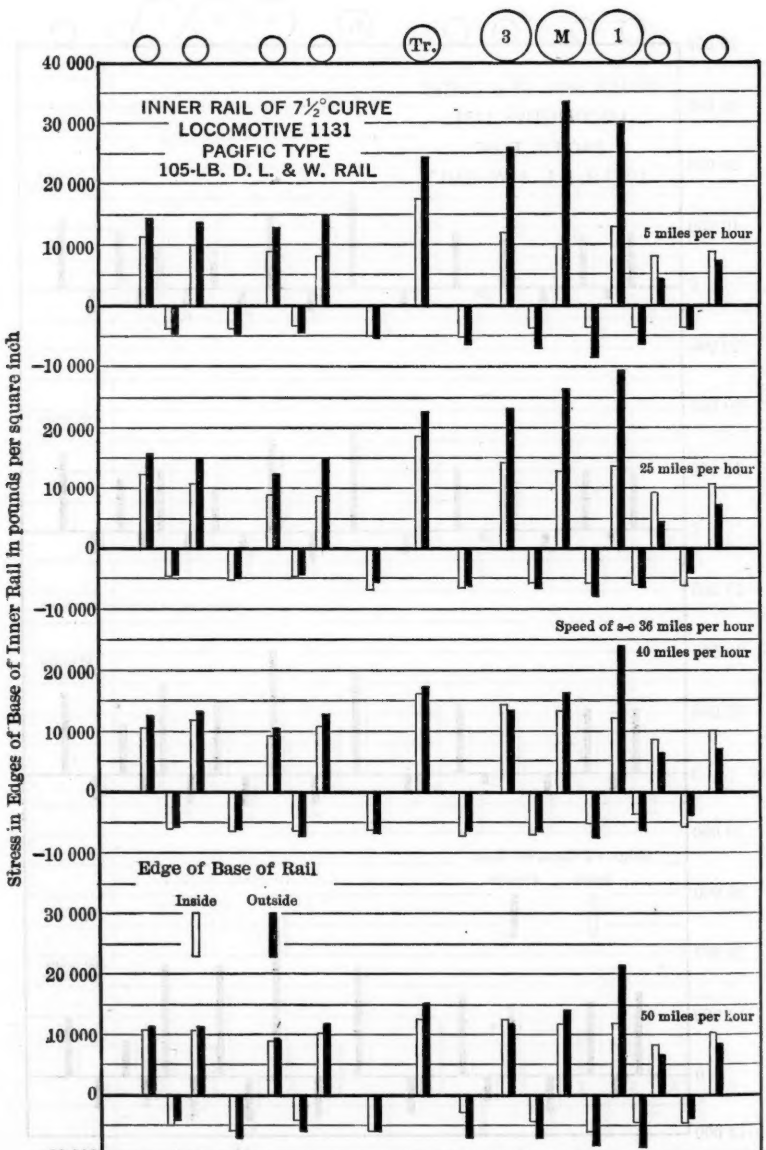


FIG. 60.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER RAIL OF THE 7½° CURVE, SERIES 5117–5135, PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

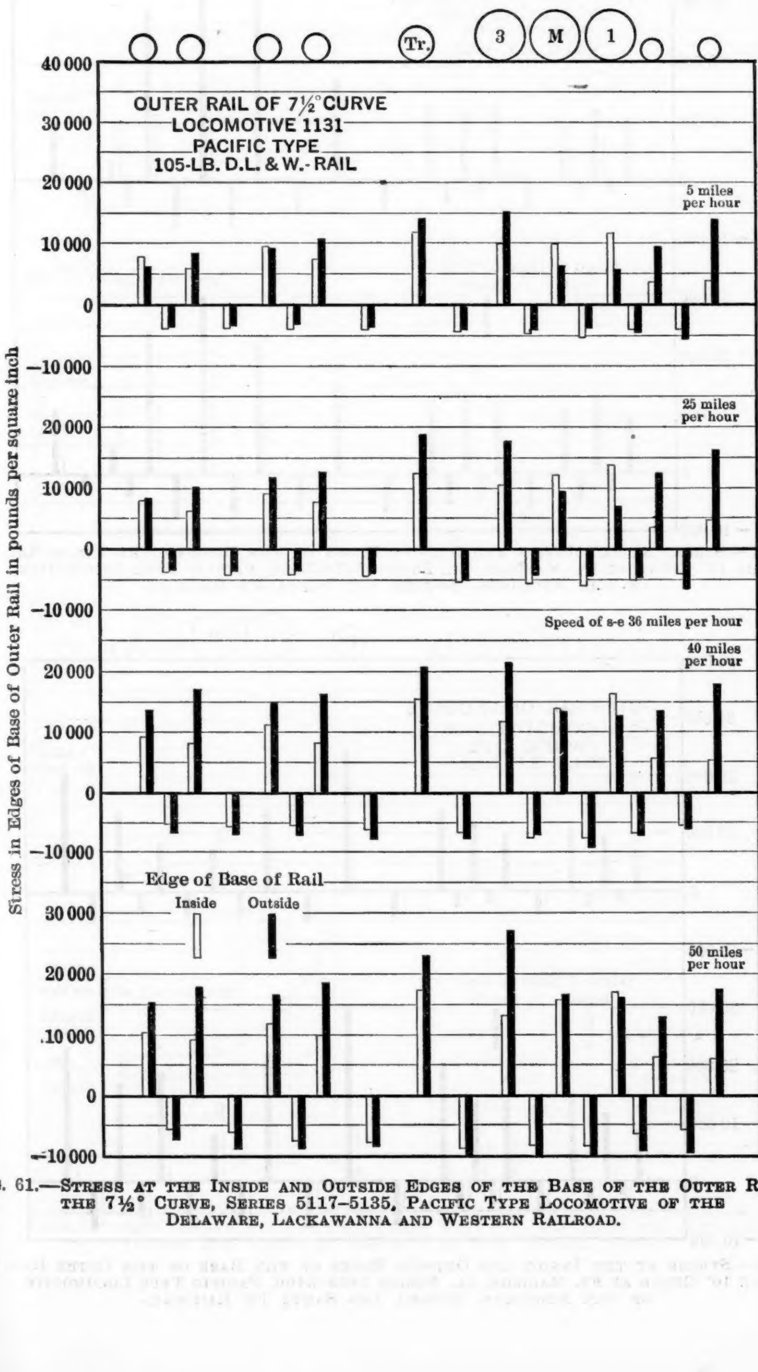


FIG. 61.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE OUTER RAIL OF THE 7½° CURVE, SERIES 5117–5135, PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

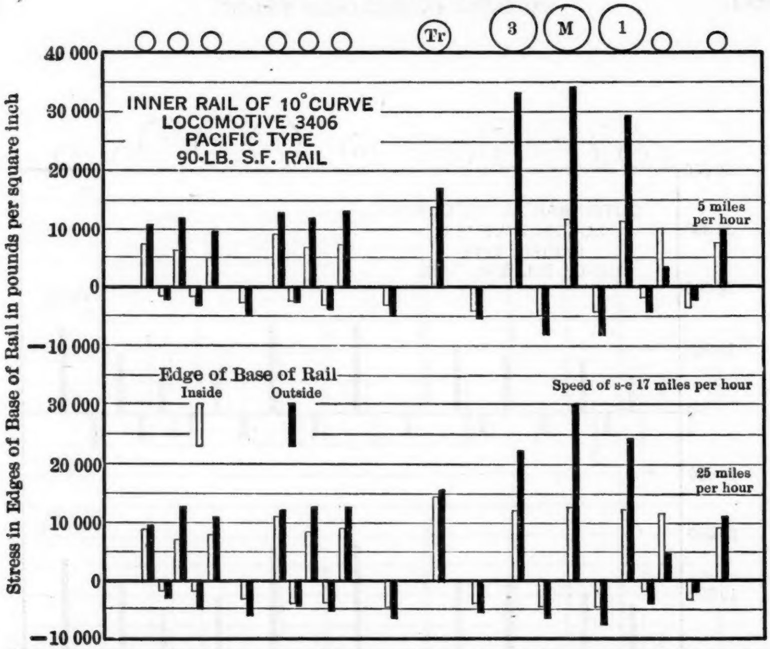


FIG. 62.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER RAIL OF THE 10° CURVE AT FT. MADISON, IA., SERIES 5459–5466, PACIFIC TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

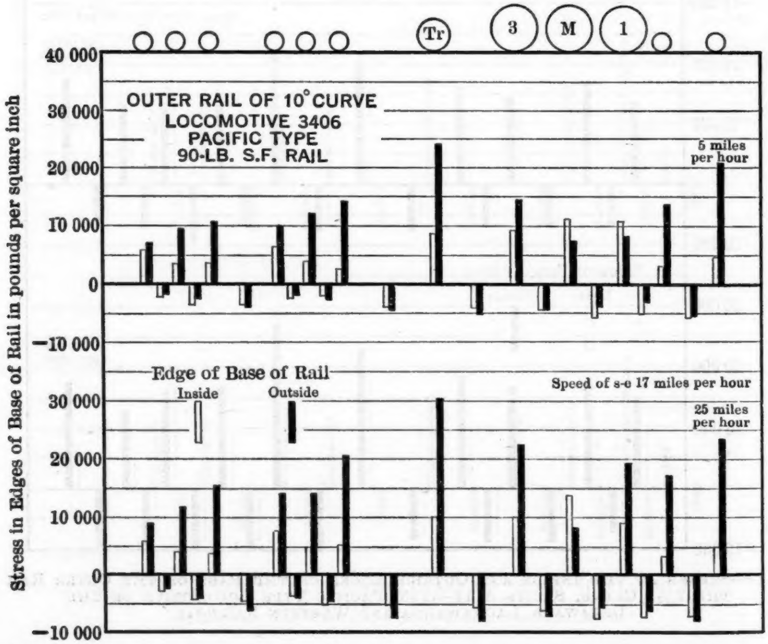


FIG. 63.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE OUTER RAIL OF THE 10° CURVE AT FT. MADISON, IA., SERIES 5459–5466, PACIFIC TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

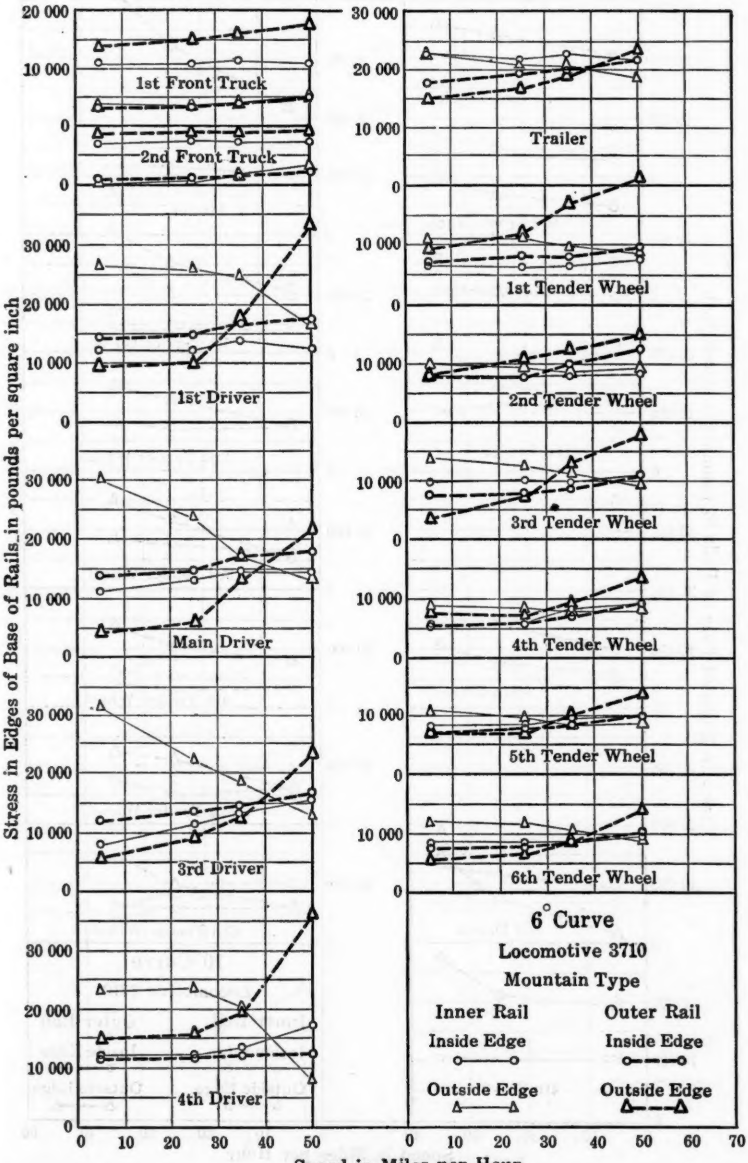


FIG. 64.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 6° CURVE WITH THE MOUNTAIN TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY AT THE SEVERAL SPEEDS.

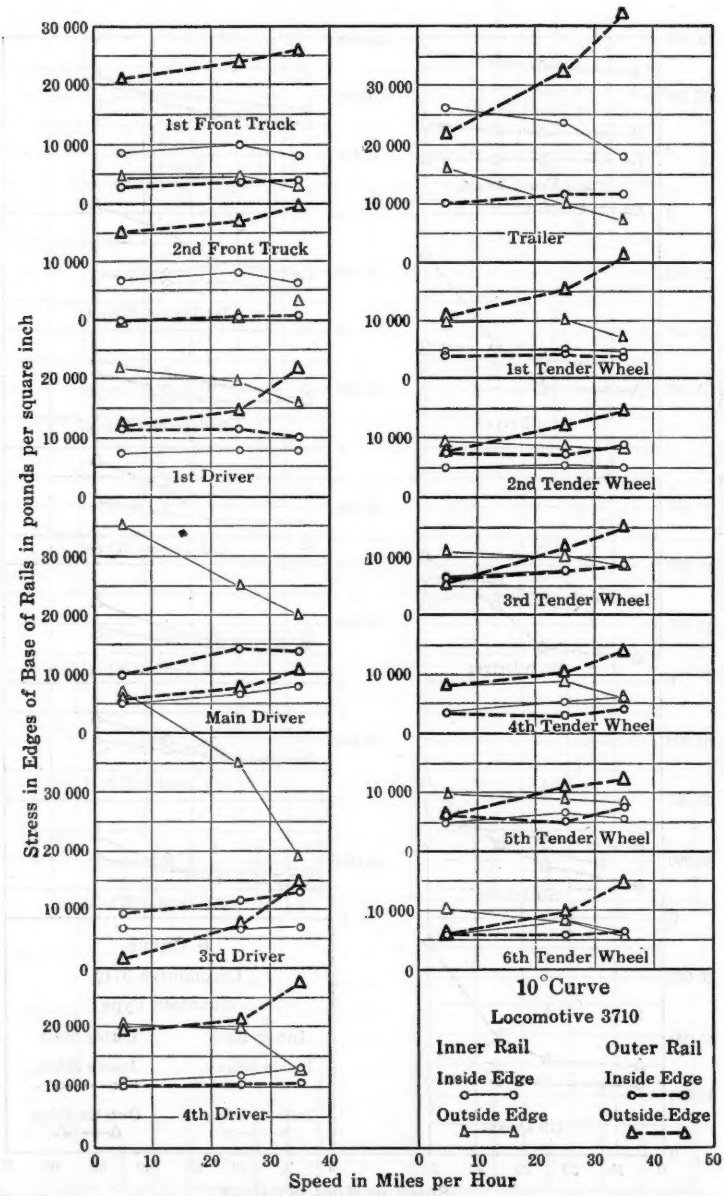


Fig. 65.—Stress at the Inside and Outside Edges of the Base of the Inner and Outer Rails of the 10° Curve with the Mountain Type Locomotive of the Atchison, Topeka and Santa Fe Railway at the Several Speeds.

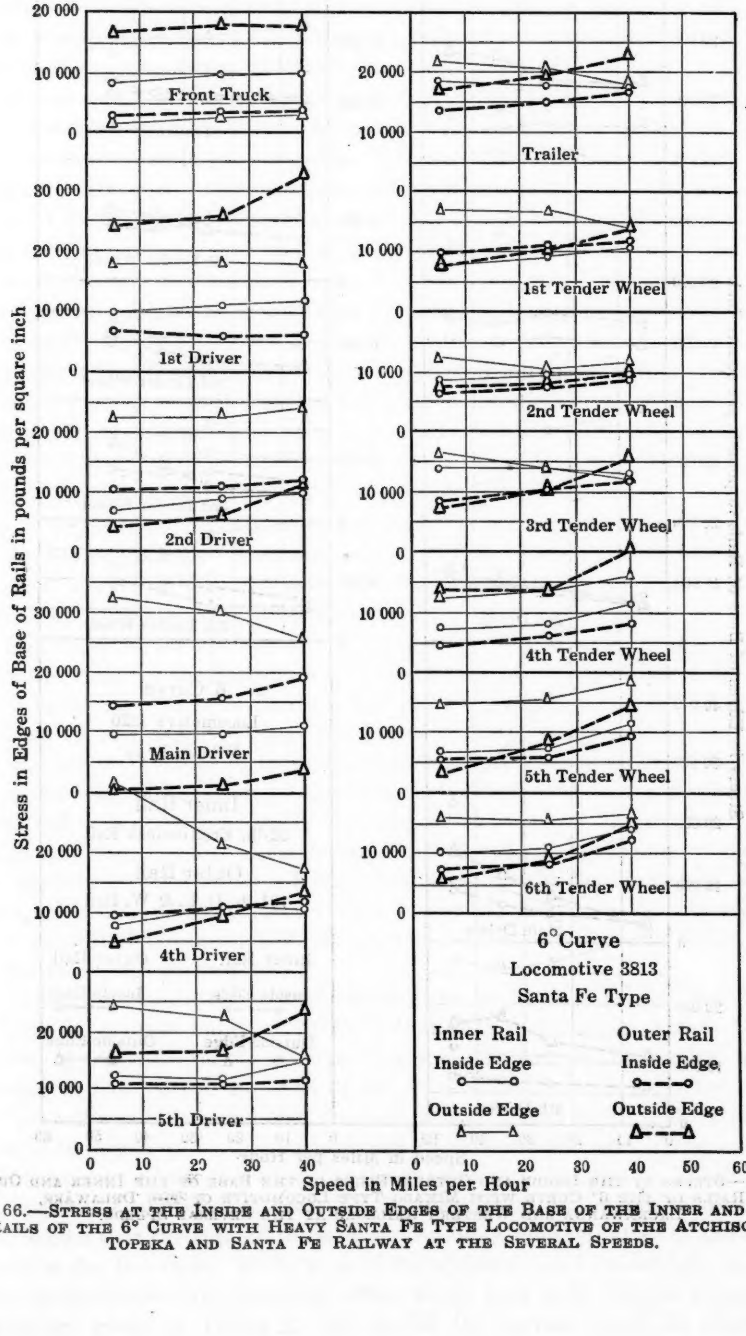


FIG. 66.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 6° CURVE WITH HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY AT THE SEVERAL SPEEDS.

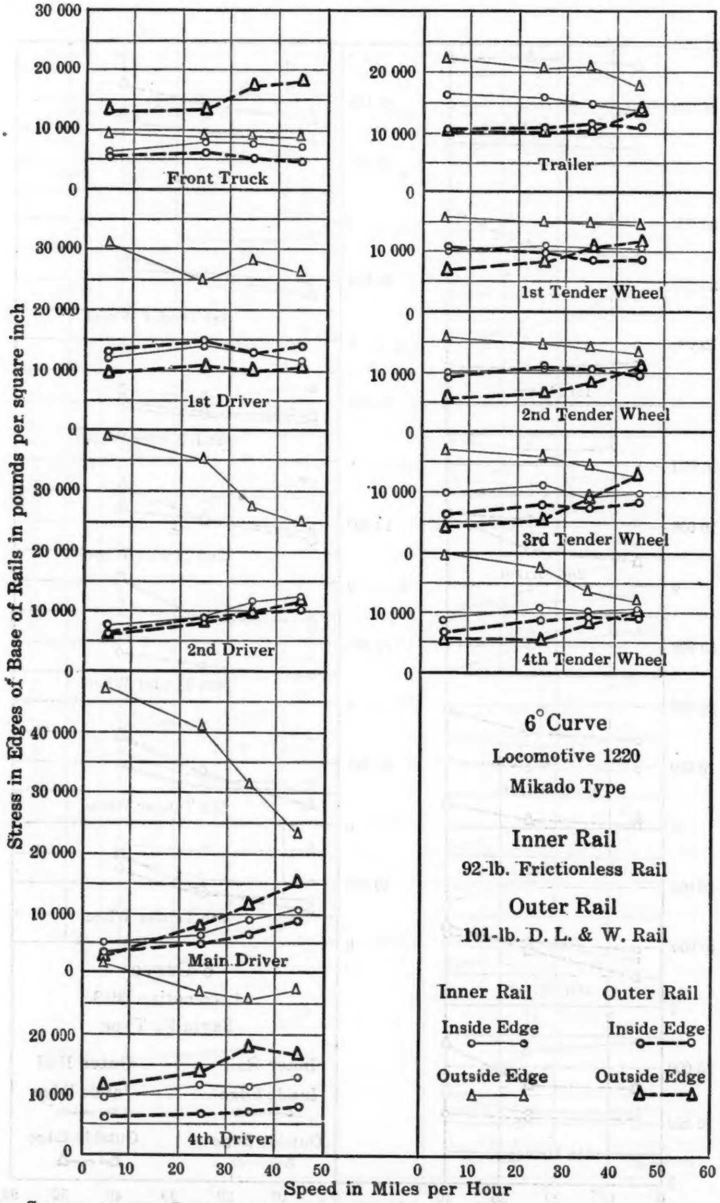


FIG. 67.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 6° CURVE WITH MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD AT THE SEVERAL SPEEDS.

tative of the bending of the rail in a vertical plane, or, more strictly, of the bending in a direction normal to the inclination of the track, the two effects being practically identical for the super-elevation of the track used in the tests as the cosine of the angle of inclination is very close to unity. Although stresses in rail are not exactly proportional to the loads when the same total load is differently distributed among the several wheels or differently divided between the two rails, yet, when the differences are not great, the sum of the stresses in the rail under all the wheels will generally not differ greatly for different divisions or distribution of load, and summations of the stresses for each rail may be useful for making comparisons and in checking the action of the locomotive and track. By means of the analytical method given in the first progress report and the solution for unknowns in equations based thereon, the load which will produce the given mean stress may be estimated quite approximately. It will be seen, therefore, that the values of the mean stresses in base of rail (vertical bending stresses) not only will permit comparisons with the stresses in straight track to be made, but will enable the vertical load to be distinguished from the lateral forces or loads that are also developed in passing around the curve. A close estimate may then be made of the distribution of vertical load among the wheels and between the two rails as it is found on the various curves. Two discussions will be given, the first based on the average stresses in the two rails, and the second based on the loads at the individual wheels and the stresses in the rails.

Fig. 68 gives the average of the vertical bending stresses in the inner and the outer rails for the Mountain type locomotive on the 6° curve of the Atchison, Topeka and Santa Fe Railway and also the average vertical bending stress in base of rail found on straight track with the same locomotive. These stresses are the average of those found throughout the revolution of the driver. It is seen that the average of the vertical bending stresses for the inner and outer rail does not differ greatly from the stress found on straight track. Generally speaking, in most of the tests on the curved track, the sum of the vertical bending stresses under all the wheels was nearly that found on straight track, although in some cases it was somewhat larger on the curved track. It is evident that the total of the vertical load effects does not differ greatly in the two kinds of tracks.

It may be interesting to find whether the load is divided between the two rails in the manner indicated by Equations (31) and (32), in Article 12, "The Action of Curved Track". For this purpose, the sum of the vertical bending stresses in base of rail for each of the drivers, trailer, and front truck wheel on one rail was taken, and also the sum of the vertical bending stresses in the base of the other rail. The ratio found by dividing the sum in the outer rail by the average of the two sums for the various tests is given in Tables 21 and 22, as is the corresponding ratio for the inner rail. In subsequent discussion, it is shown that the sum of the stresses is closely representative of the relative loads on the two rails. If the sum of the stresses found on straight track was used as the divisor, the resulting ratios would have quite similar values. The ratios are given in Tables 21 and 22 for the various speeds at which tests

were made. The ratios calculated by Equations (31) and (32) are also given in these tables.

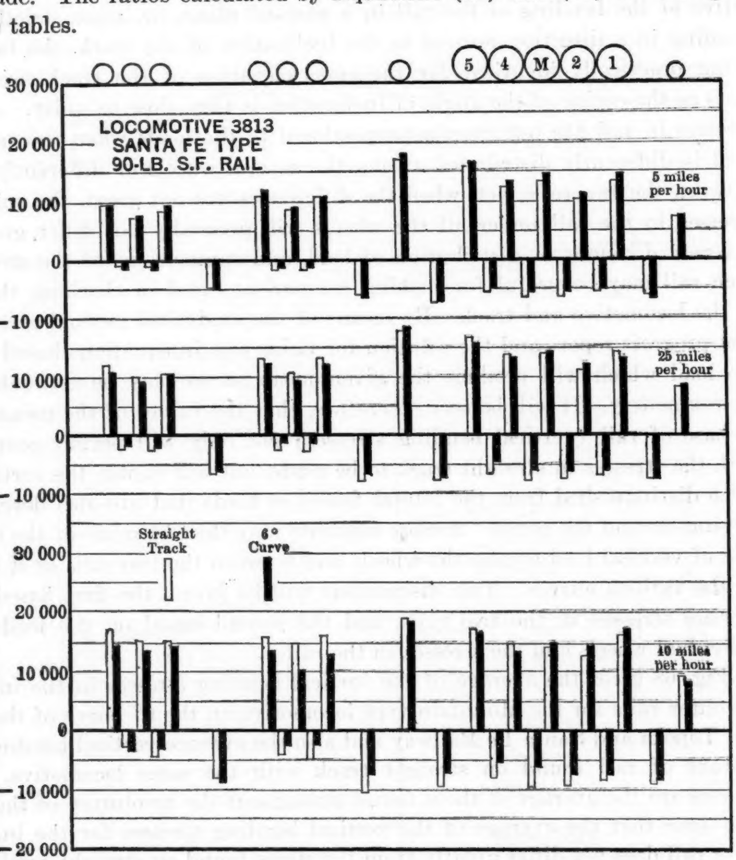


FIG. 68.—VALUES OF THE AVERAGE OF THE STRESSES IN THE INNER AND OUTER RAIL OF THE 6° CURVE AND THE AVERAGE STRESS ON STRAIGHT TRACK, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

For the lower speeds, it is seen that the division of stress between the two rails (and presumably also the division of load) for the Pacific type on the 4° and $7\frac{1}{2}$° curves of the Delaware, Lackawanna and Western Railroad and the Mountain type and Heavy Santa Fe type on the 6° and 10° curves of the Atchison, Topeka and Santa Fe Railway agree very closely with the ratios calculated from the inclination of track and centrifugal force, thus confirming the analysis. The stresses observed under the Mikado type on the 4° curve at the lower speeds give ratios which are much closer to unity than the calculated ratios; it is not known why these differ; for the $7\frac{1}{2}$° curve the agreement is close. The Pacific type of the Atchison, Topeka and Santa Fe Railway, on the 10° curve, with a super-elevation of 2 in., gives ratios of observed stresses which vary from unity by an amount that is about twice as great as the calculated ratios. It appears from this that, for slight super-elevation, curvature alone gives an effect in changing the division of load between the two rails greater than that

found from the inclination of track and the centrifugal force. Evidently, there is some transfer of load by other means, possibly the action of the equalizing levers.

For the higher speeds, above those corresponding to the speeds of super-elevation, more variation in the results are found. The observed stresses give ratios which correspond to those obtained by analysis in the case of the Mikado type locomotive on the 4° curve, the Pacific type on the 4° curve, the Mountain type on the 6° and 10° curves, and the Heavy Santa Fe type on the 10° curves. Others give seemingly inconsistent ratios at the higher speeds; the Mikado type locomotive on the 7½° curve gives ratios derived from the test values which are larger than those obtained from the analytical values.

As the summation of the stresses under the wheels of the locomotive for each rail may be taken to represent closely the relative loads on the inner and outer rail, it is evident that at the lower speeds, except for the 10° curve with only 2 in. of super-elevation, the division of the total load between the inner and outer rails is closely represented by the calculated values based on the transverse inclination of track and the centrifugal force. The distribution of load among the several wheels and even its division between the two wheels of one axle are quite different matters, and important variations from the distribution found on straight track will be noted.

Consideration will now be given to the vertical bending stresses under the individual wheels and the loads necessary to produce them.

The vertical bending stress in base of rail under the various wheels of the locomotive (the average stress throughout the revolution of the driver) is recorded in Figs. 69 to 72 for both outer and inner rails for the speeds used in the tests on curved track. Comparison may be made with the stresses under the same wheels in the tests on straight track, as given in Figs. 10 to 20, inclusive, and in Tables 10 to 18, inclusive. In making a study of the stresses, it should be kept in mind that changes in values of the vertical bending stresses at any wheel must be due to changes in the amount of load on the wheel either by itself or in combination with adjoining wheels.

Values of the wheel loads necessary to produce the observed vertical bending stresses may be calculated by the use of the analytical method for determining the stress in rail caused by a group of wheel loads given in the first progress report. An algebraic equation is written for the vertical bending stress at each driver; the observed vertical bending stress at the driver is a known quantity, and the unknown wheel loads of the several drivers are represented as unknown quantities. There will then be as many equations and unknown quantities as there are drivers. The effect of the trailer and the wheels of the front truck is taken into account whenever necessary. The solution of these equations is not troublesome. The fact that the sum of all the loads thus found agrees quite closely with the total load on the drivers should give some confidence in this method of calculating the division of load among the wheels.

In Table 23 are given the calculated vertical wheel loads on straight track and on the inner and the outer rail of curves for several types of locomotives at a speed of 5 or 10 miles per hour as determined by this method. The results

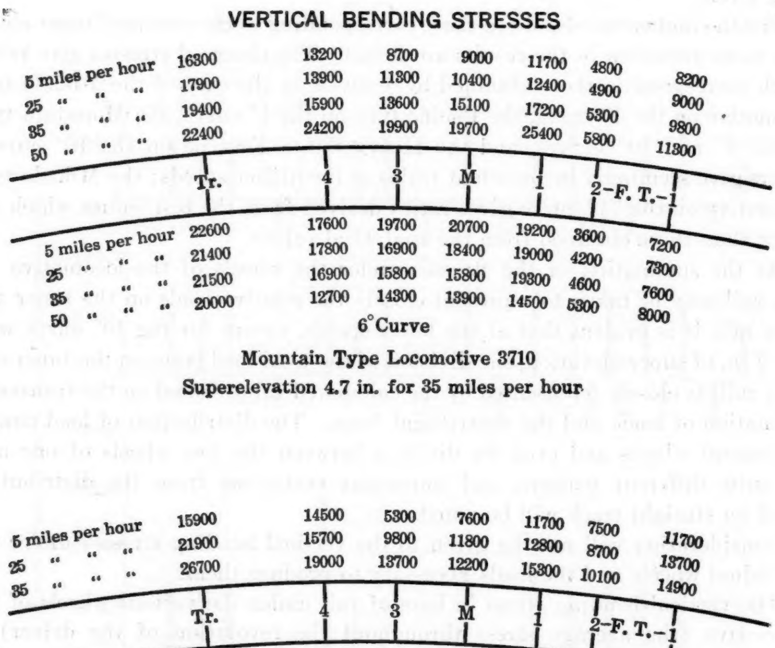


FIG. 69.—VERTICAL BENDING STRESSES IN BASE OF RAILS OF CURVED TRACK, MOUNTAIN AND PACIFIC TYPE LOCOMOTIVES OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

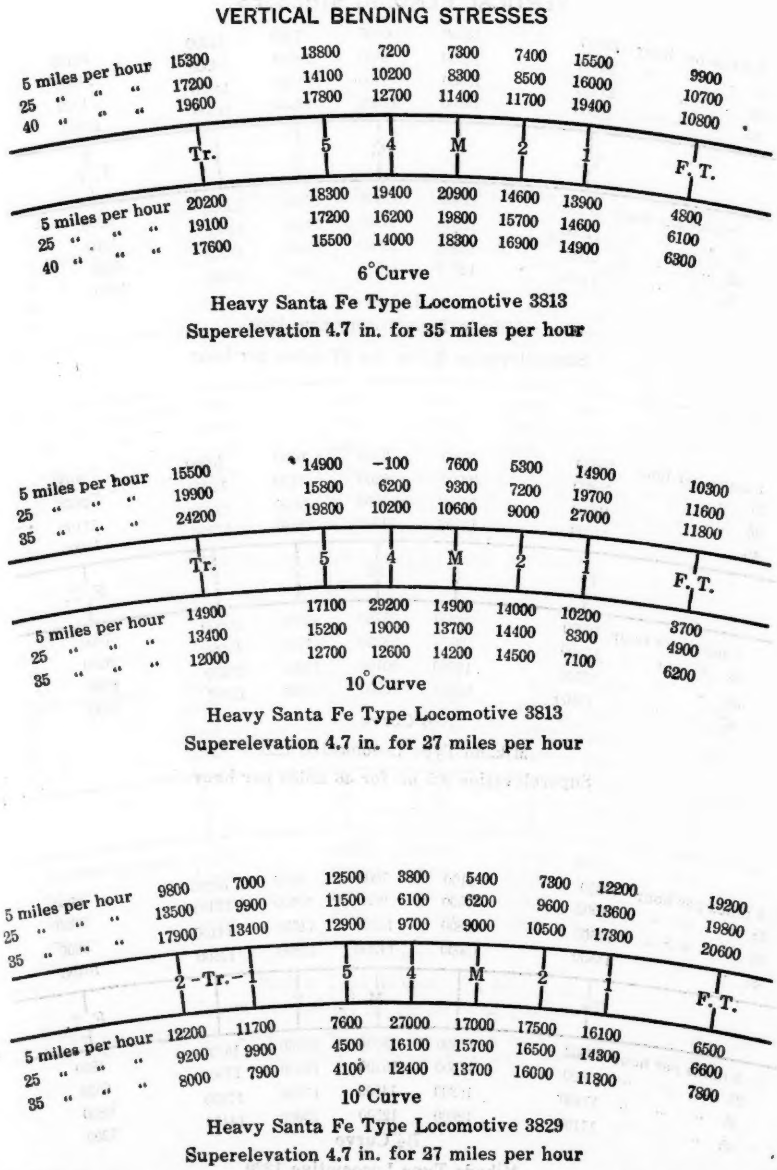


FIG. 70.—VERTICAL BENDING STRESSES IN BASE OF RAILS OF CURVED TRACK, HEAVY SANTA FE TYPE LOCOMOTIVES OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

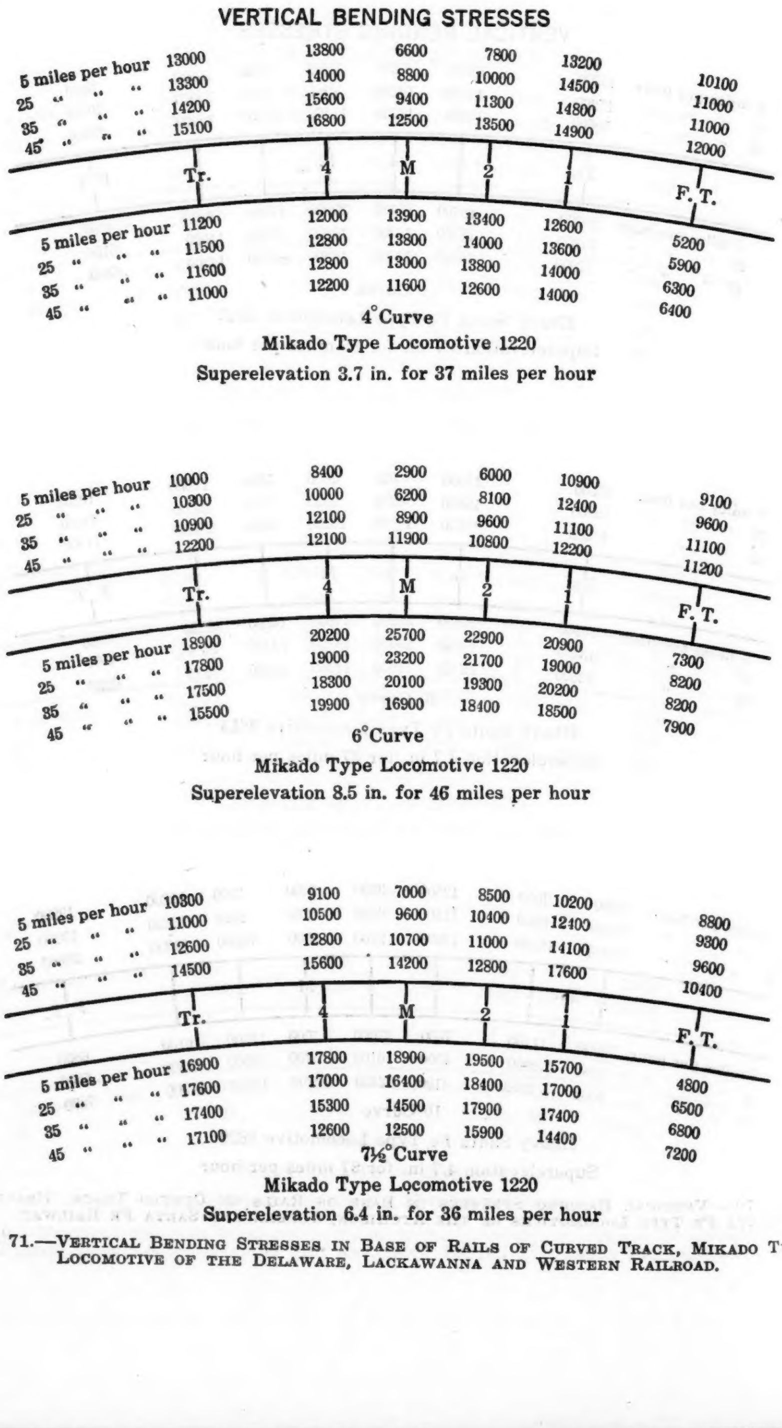


FIG. 71.—VERTICAL BENDING STRESSES IN BASE OF RAILS OF CURVED TRACK, MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

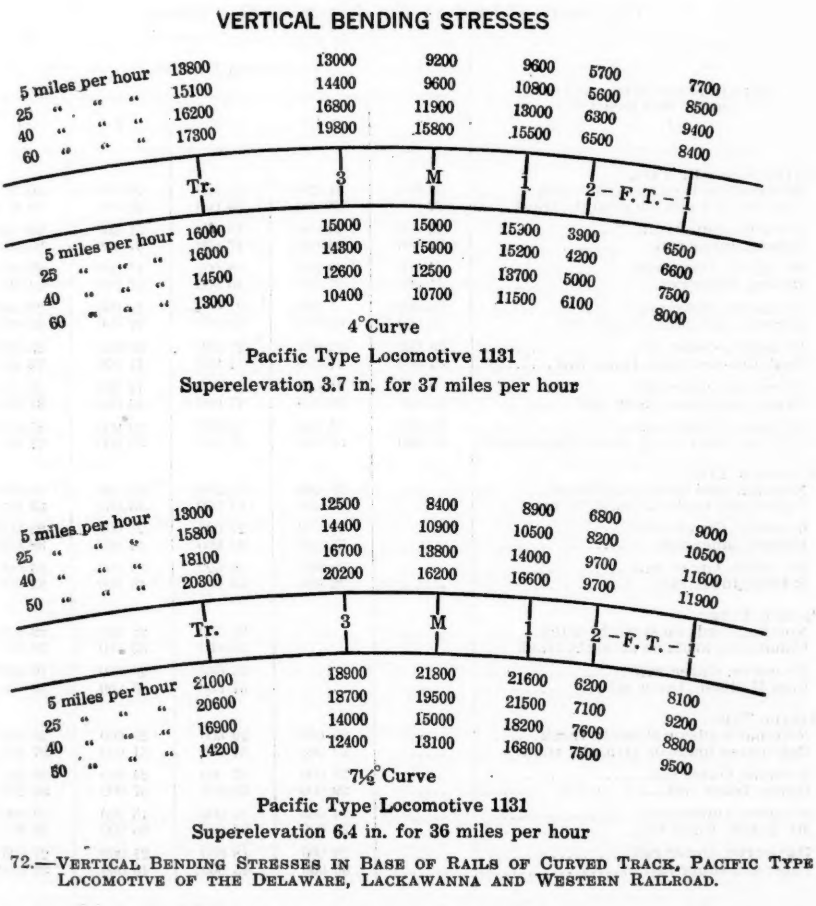


FIG. 72.—VERTICAL BENDING STRESSES IN BASE OF RAILS OF CURVED TRACK, PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

of the calculations were changed proportionally to make the sum of the wheel loads equal the total load on the drivers. The values given in Table 23, although subject to some error, may be taken as representative of the vertical loads transmitted to the rail. The same method, of course, may be applied to any speed.

TABLE 23.—VERTICAL LOADS ON DRIVERS CALCULATED FROM OBSERVED VERTICAL BENDING STRESSES FOR SPEEDS OF 5 AND 10 MILES PER HOUR.

The nominal load on the drivers is also given.

Type of locomotive, degree of curve, and location.	Driver Number.				
	5	4	3	2	1
Heavy Santa Fe Type:					
Nominal loads on straight track	32 000	31 200	31 500	29 800	30 200
Calculated loads, on straight track	32 000	33 000	33 000	29 000	28 000
6° curve. Outer rail	25 000	20 000	19 000	21 000	29 000
Ribera, Inner rail	37 000	46 000	47 000	37 000	29 000
10° curve, Outer rail	26 000	8 000	18 000	18 000	28 000
Ribera, Inner rail	41 000	64 000	45 000	37 000	24 000
10° curve, Outer rail	25 000	7 000	21 000	18 000	23 000
Bealville, up grade, Inner rail	35 000	60 000	50 000	37 000	26 000
10° curve, Outer rail	25 000	16 000	22 000	20 000	25 000
Bealville, wet rails, Inner rail	32 000	45 000	44 000	41 000	32 000
10° curve, Outer rail	9 000	21 000	22 000	17 000	24 000
Cajon, up grade, Inner rail	52 000	33 000	47 000	46 000	31 000
10° curve, Outer rail	25 000	16 000	20 000	20 000	27 000
S. P. locomotive, up grade, Inner rail	29 000	50 000	47 000	36 000	27 000
Mountain Type:					
Nominal load on straight track	......	30 200	30 200	30 400	30 700
Calculated loads on straight track	......	29 000	31 000	33 000	29 000
6° curve, Outer rail	......	22 000	21 000	21 000	22 000
Ribera, Inner rail	......	33 000	42 000	44 000	38 000
10° curve, Outer rail	......	23 000	16 000	19 000	23 000
Ribera, Inner rail	......	32 000	53 000	45 000	32 000
Pacific Type:					
Nominal loads on straight track	......	......	30 700	29 200	29 900
Calculated loads on straight track	......	......	28 000	32 000	30 000
10° curve, Outer rail	......	......	20 000	20 000	19 000
Fort Madison, Inner rail	......	......	37 000	45 000	39 000
Mikado Type:					
Nominal loads on straight track	......	29 600	29 600	29 600	29 600
Calculated loads on straight track	......	29 000	31 000	31 000	27 000
4° curve, Outer rail	......	29 000	22 000	24 000	28 000
Dover, Inner rail	......	29 000	38 000	37 000	30 000
6° curve. Outer rail	......	14 000	10 000	15 000	19 000
Mt. Tabor, Inner rail	......	38 000	53 000	50 000	38 000
7½° curve, Outer rail	......	18 000	18 000	21 000	20 000
Paterson, Inner rail	......	36 000	45 000	46 000	33 000

It is evident from the diagrams and tables that the changes in vertical bending stresses and in vertical loads at the several drivers are very marked and that important additions to the bending moments in the rail and in the bearing pressures at the top of the rail are found on curves. The increased stress in the inner rail under certain drivers is greatest at the low speed, but even at speeds two-thirds that corresponding to super-elevation increases of stress of 75 to 85% of the increase found at the low speed were common. At the higher

speeds, the special increase in load at the one driver vanishes, and the distribution among the several drivers is much the same as would be expected from a consideration of transverse inclination of track and centrifugal force, except that the vertical bending stress in the outer rail under the outer front driver is very great at the high speeds.

Consider the results for the Heavy Santa Fe type locomotive given in Fig. 70. At 5 miles per hour, the vertical bending stresses in the inner rail of the 6° curve under the third and fourth drivers are much higher than the corresponding ones in the outer rail—far higher than are to be expected from considerations of transverse inclination of track and centrifugal force. In Table 23 it is seen that the loads transmitted by these inner drivers estimated from the observed vertical bending stresses are 47 000 and 46 000 lb., 50% greater than the nominal loads. On the 10° curve at Ribera, at 5 miles per hour, the vertical bending stress in the inner rail under the fourth driver is 29 000 lb. per sq. in. By calculation from the stresses, the load transmitted by this driver is estimated to be 64 000 lb. (see Table 23), more than twice the normal load. The stresses in the outer rail under wheels on the same axles are correspondingly light, the stress under the fourth driver on the 10° curve being zero. Considering the stresses under adjoining wheels, the load on the driver giving a rail stress of zero is calculated to be 8 000 lb., about one-fourth that acting on straight track. For both curves the high stresses in the inner rail become smaller at the higher speeds, and at 35 and 40 miles per hour (above the speed of super-elevation), they are fairly uniform under the several drivers. On the 10° curve, the vertical bending stresses in the outer rail under all the drivers increase with the increase in speed. The stress of 27 000 lb. per sq. in. under the first driver at a speed of 35 miles per hour is the highest vertical bending stress found in the outer rail, and the corresponding calculated load is 47 000 lb.

In the Mountain type locomotive (Fig. 69), the vertical bending stresses in the inner rail of the 6° curve under the second and third drivers at a speed of 5 miles per hour are $2\frac{1}{3}$ and $2\frac{1}{4}$ times those in the outer rail. This means loads of 44 000 and 42 000 lb., 40% more than the normal load on straight track—far more than will be produced by transverse inclination of track alone. On the 10° curve, the corresponding vertical bending stress in the inner rail under the second driver is nearly three times as great as that in the outer rail and under the third driver five times as great. This means loads of 45 000 and 53 000 lb., 50% more than on straight track for the second driver and 75% for the third driver, the latter driver thus giving a very high bearing pressure on the rail. At the speed of 35 miles per hour, the stresses in the two rails of the 6° curve under the various wheels have approached each other and are nearly equal. A somewhat similar condition exists on the 10° curve for the two rails, although the tendency to high stresses in the outer rail under the first and last driver is present with this locomotive, as with the Heavy Santa Fe type. At the speed of 25 miles per hour, the calculated load on the third driver on the inner rail of the 10° curve is 42 000 lb. On the 6° curve, at 50 miles per hour, the vertical bending stress in the outer rail at the first driver is 25 400 lb. per

sq. in. and that at the fourth driver, 24 200 lb. per sq. in. The trailer of the Mountain type gives high stresses in one rail or the other, the highest value being reached in the outer rail of the 10° curve at 35 miles per hour. It is seen that except for the trailer the speed that is higher than that corresponding to the super-elevation gives the most uniform values of the stresses under all the wheels and in the two rails.

The Pacific type locomotive on the 10° curve at Fort Madison, Iowa, (Fig. 69), develops a vertical bending stress in the inner rail under the first driver at a speed of 5 miles per hour that is 2.2 times that in the outer rail, and one under the second driver that is 2.4 times the corresponding stress in the outer rail. The loads necessary to produce these stresses in the inner rail (39 000 and 45 000 lb.) are 1.3 and 1.5 times the normal loads on these two drivers (the driver loads that apply to straight track), although the calculated ratio (see Tables 21 and 22) of load on inner rail to normal load for the super-elevation of 2 in. is only 1.08. At 25 miles per hour (the speed corresponding to the super-elevation is 17 miles per hour), the vertical bending stress in the inner rail under the main driver is still nearly double that in the outer rail and the corresponding calculated loads are 40 000 and 24 000 lb. The distribution of load among the drivers at both speeds is evidently considerably different from that which obtains on straight track. It seems that for this sharp curve and small super-elevation the equalizing system does not act to give an equal distribution of load among the drivers. The Pacific type locomotive on the 4° curve of the Delaware, Lackawanna and Western Railroad, at 5 miles per hour, develops vertical bending stresses in the inner rail under the first and second drivers that are 1.6 times the corresponding stresses in the outer rail. These stresses indicate that the loads on these two drivers, 39 000 and 41 000 lb., are 20 and 25% greater than the normal load, although the calculated ratio (and also the ratio of observed values for the locomotive as a whole) is only 1.15. On the 7½° curve, at 5 miles per hour, the same drivers develop vertical bending stresses in the inner rail 2.4 and 2.6 times those in the outer rail; the corresponding loads on the inner rail are 46 000 and 49 000 lb., 40 to 50% greater than the normal loads, while the ratio calculated from the transverse inclination of the track is only 1.27. On both the 4° and the 7½° curves, at speeds at and slightly above those corresponding to super-elevation, the vertical bending stresses in both rails under all the drivers of this locomotive approach common values, showing that the distribution of load is much the same as that given by the equalizing levers on straight track.

The Mikado type locomotive of the Delaware, Lackawanna and Western Railroad, which has the first and second, and also the third and fourth drivers connected by equalizing levers, shows a different distribution and grouping of the stresses. The ratios of the vertical bending stress in the inner rail of the 4° curve, at 5 miles per hour, to stress on straight track derived by the analysis and calculation are in the order of the drivers 1.04, 1.22, 1.26, and 1.04. For each two drivers that are connected by equalizers, the ratio is higher for the intermediate driver than for the front or rear one, but the average

is close to 1.15, the value calculated from the inclination of track. On the $7\frac{1}{2}°$ curve, at 5 miles per hour, the same transfer of load from first to second driver and from fourth to third occurs. The ratios of stress in inner rail to stress in outer rail are 1 5, 2.3, 2.7, and 2.0, respectively. The corresponding loads on the inner rail are 33 000, 46 000, 45 000, and 36 000 lb. These loads show that there is a considerable increase in the bearing pressure on the inner rail over its normal value. For the higher speeds, the stresses in the two rails are much the same for all the drivers. For the 6° curves, the loads on the second and third drivers on the inner rail calculated from the stresses, at 5 miles per hour (see Table 23), are 50 000 and 53 000 lb., respectively, and at 25 miles per hour, 45 000 and 47 000 lb.

It is seen that for all the curves the relation of the average of the vertical bending stresses under all the wheels of a locomotive on the inner rail to the corresponding average of the stresses in the outer rail, taken as a measure of the bending of the rail in a vertical plane, in the main conform fairly closely to what may be expected from the analytical consideration of the transverse inclination of the track and the centrifugal force, as far as the locomotive as a whole is concerned. The principal variation from this conformity to analysis is the Pacific type locomotive on the 10° curve having a super-elevation of 2 in.

The outstanding result of the foregoing study of vertical bending stresses on curved track is the variable distribution of load among the drivers, and, particularly, the greatly increased loads found on some of the drivers beyond that normally expected. These high loads occur principally on the inner rail and are most marked at the low speed, although high values were found in a number of cases at speeds two-thirds that corresponding to the super-elevation. Further examples of high loads under individual drivers at moderate speeds are cited in the discussion of the tests in California (see Article 20, "Results of Tests on 10° Curves in California"). Loads ranging up to 100% in excess of the normal load were found with several of the locomotives. These excessive loads produce high stresses in the rail, but more important still they give very high bearing pressures on the rail. It is a well known fact, of course, that the inner rail of curves suffers greatly from the high pressure on it. The bearing pressures on the rail on straight track constitute a serious problem, and the conditions on the curves seem to be far worse than they have been thought to be. As the bearing pressures found are considerably higher under some of the wheels than those which ordinary analysis of the effect of transverse inclination of track and centrifugal force would predict, it would seem well to have a study made of the action of the equalizing levers and the springs on curved track to try to find the cause of the concentration of load, and to attempt to modify the design so as to obviate such gross inequalities.

15.—Lateral Bending of Rail on Curves.—When forces are applied laterally to the rails of a curve by the wheels of the locomotive (the component forces in the direction of the radius of the curve, either inward or outward, being meant), lateral bending of the rail is produced and a set of stresses is developed which may be termed lateral bending stresses. As the beam strength of the rail in a lateral direction is much less than that which resists bending in a

vertical direction (the section modulus, $\frac{I}{c}$, about a vertical axis being only about one-fifth of that about a horizontal axis), large lateral bending stresses will be developed by a lateral bending moment relatively much smaller than the vertical bending moment that causes vertical bending stresses of the same magnitude. The stress in any fiber, of course, will be the sum of the fiber stress due to vertical bending and that due to lateral bending, the nature of the stress either tension or compression being taken into consideration. It will help in understanding the cause of the lateral bending and in applying the analysis given in Article 12, "The Action of Curved Track", if something is known of the position and direction taken by the wheels of the locomotive in traversing a curve.

In Figs. 73 and 74 are shown the relative positions of the wheels of five locomotives on several curves, the dimensions are given in inches and represent the distance from the gauge side of the rail to the flange of the wheel. The measurements were made with a view of obtaining a general notion of the position and direction taken by the wheels, but no effort was made to secure great accuracy or completeness in the tests and measurements. The results, however, may be taken to be fairly accurate. The locomotive was run over the track at slow speed and allowed to come to rest without the application of the brakes. The test was not repeated. On the Atchison, Topeka and Santa Fe Railway, measurements were made between the gauge side of the rail and the flange of the wheel. A steel scale was used and notwithstanding the difficulties of measurement the data are probably accurate to $\frac{1}{16}$ in. On the Delaware, Lackawanna and Western Railroad, no measurements were made except for the last diagram of Fig. 74, but observations were taken to see whether the flange bore on the side of the rail, or was away from it a distance less than or more than $\frac{1}{2}$ in. The radial line on Figs. 73 and 74 is drawn at the position where the radius of the curve is perpendicular to the line taken by the wheel-base, the determination being made on a large scale drawing. The point at which this radial line crosses the inner rail may be taken to be the probable center of rotation of the locomotive frame. Generally speaking, the flange of the outer front driver bears against or is close to the outer rail, and a line along the gauge side of the flanges of the drivers cuts the outer rail at the outer front driver or somewhat in front of it. The flange of the outer rear driver does not touch the outer rail and in several cases the flange of the inner rear driver is closer to the rail than that of the outer one. The flange of the inner front driver is well away from the rail. Generally, too, the flange of the driver next to the rear one is close to the inner rail, although it does not bear against it as the outer front driver bears against the outer rail. The center of rotation (if this is the center of rotation) is the point at which the radial line marked on the diagrams crosses the inner rail. For the locomotives having eight or ten drivers, this point is located on the inner rail at the driver next to the rear driver. Locomotive No. 3710, on the 10° curve, appears to be an exception to this; the point is here found under the second driver. In the case of the Pacific type locomotive, one diagram shows

the point to be at the rear driver and one between the second and third driver. The former has the front driver flange against the outer rail; in the second one, it is well away from it.

The flange of the outer wheel of the front truck generally bears against the outer rail. In the case of the four-wheel leading truck, both outer wheels have this bearing. The flanges of the trailers do not touch the outer rail. In one case only do they touch the inner rail. They take a position away from the two rails sometimes closer to one and sometimes to the other. The first wheel of the trucks of the tender generally bears against the outer rail and the line of the wheel-base is a secant line cutting the outer rail at this point. In some cases, the front truck does not take this position; its location seems to be somewhat variable. For those trucks having the front wheel bearing against the outer rail, the center of rotation seems to be at or near the rear wheel of the truck.

The positions given in Figs. 73 and 74 may be taken to be representative of the position of the wheels at low speeds. For higher speeds, some modifications may be expected. The tendency will be for the wheels to move somewhat toward the outer rail, although it seems evident that generally there will not be much change in position with respect to the two rails. There will be, of course, an increase of the pressure of the flange of the front wheel against the rail and also a change in the amount of lateral pressure transmitted by means of friction between the wheel and the rail, but these changes may not be expected to result in any marked change in the relative position of the wheels and rails. This conclusion is borne out by the nature and amount of the lateral bending stresses found in the tests.

In Figs. 75 to 78, inclusive, is recorded the magnitude of the lateral bending stresses in the outer and inner rails under the several wheels of the locomotive and tender at the speeds at which tests were made, the stress being given in pounds per square inch, for the tests at Ribera, N. Mex., Fort Madison, Iowa, and Dover, Paterson, and Mount Tabor, N. J. This lateral bending stress is the stress by which the stress at one edge of the base of the rail exceeds that at the middle of the base of rail; its magnitude is found by taking one-half the difference between the stresses at the inside and outside edges of the base of rail. The sign in front of the stress is indicative of the nature of the lateral bending of the rail; a positive sign indicates that the bending acts to increase the curvature of the rail, the negative that the bending tends to straighten the rail. The signs apply alike to both outer and inner rail. A positive bending in the outer rail at the point of contact of a wheel implies an outward thrust against the rail at the given point; a positive bending in the inner rail implies that a lateral pull on this rail acts toward the outer rail. The diagrams give important information on the presence and nature of lateral forces and the manner of the lateral bending in the rail. Some of the outstanding features may be noted, as follows:

The lateral bending in the outer rail, under the wheels of the front truck, is found to be always positive (indicating an outward thrust) and it is generally positive also in the inner rail. This is true at all speeds. It indicates

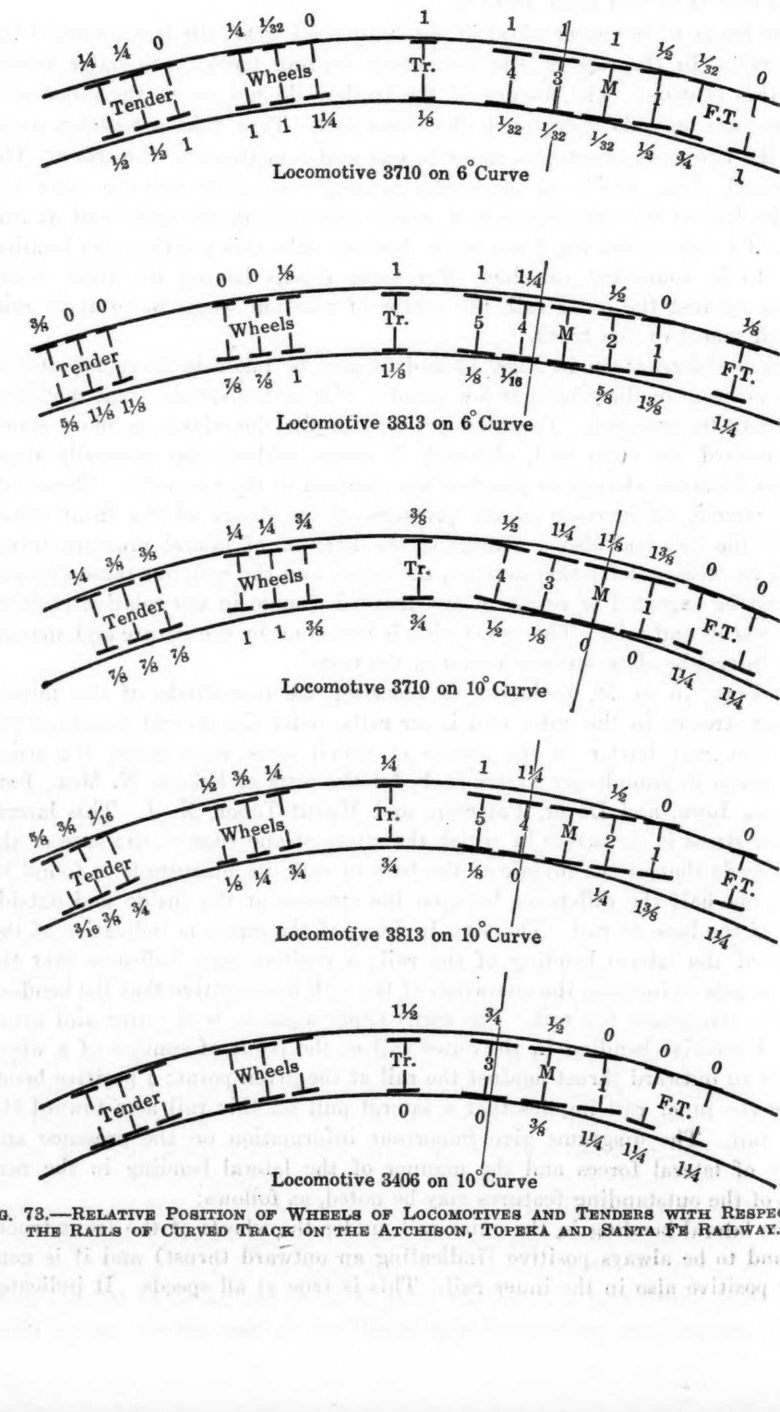


FIG. 73.—RELATIVE POSITION OF WHEELS OF LOCOMOTIVES AND TENDERS WITH RESPECT TO THE RAILS OF CURVED TRACK ON THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

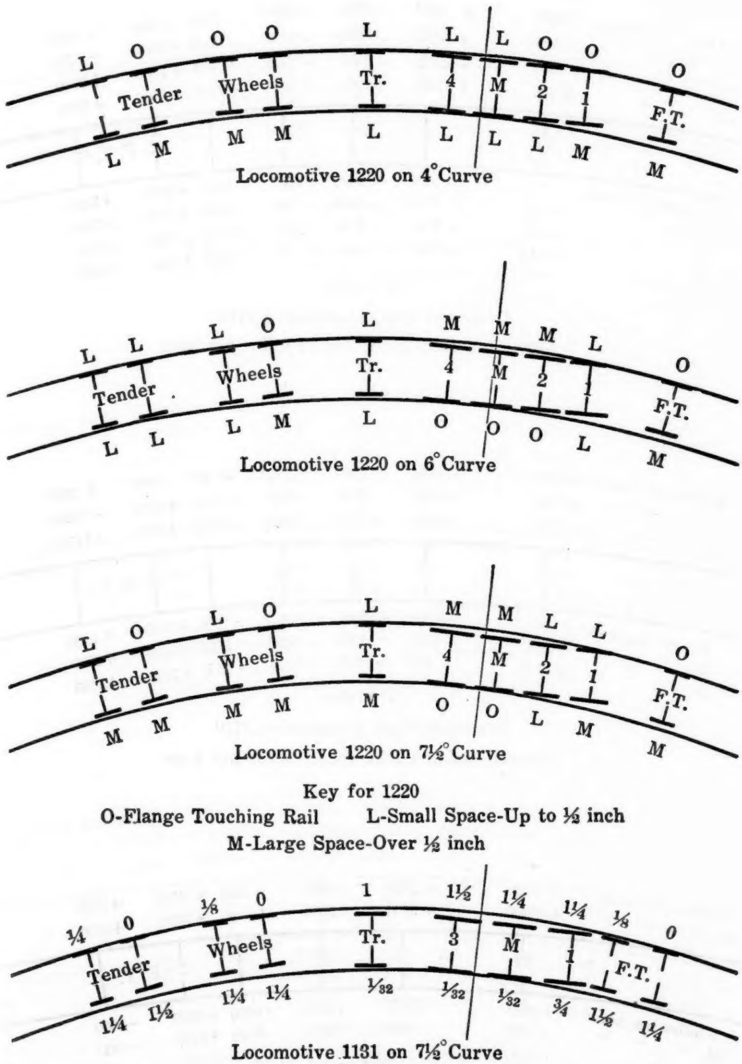


FIG. 74.—RELATIVE POSITION OF WHEELS OF LOCOMOTIVES AND TENDERS WITH RESPECT TO THE RAILS OF CURVED TRACK ON THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

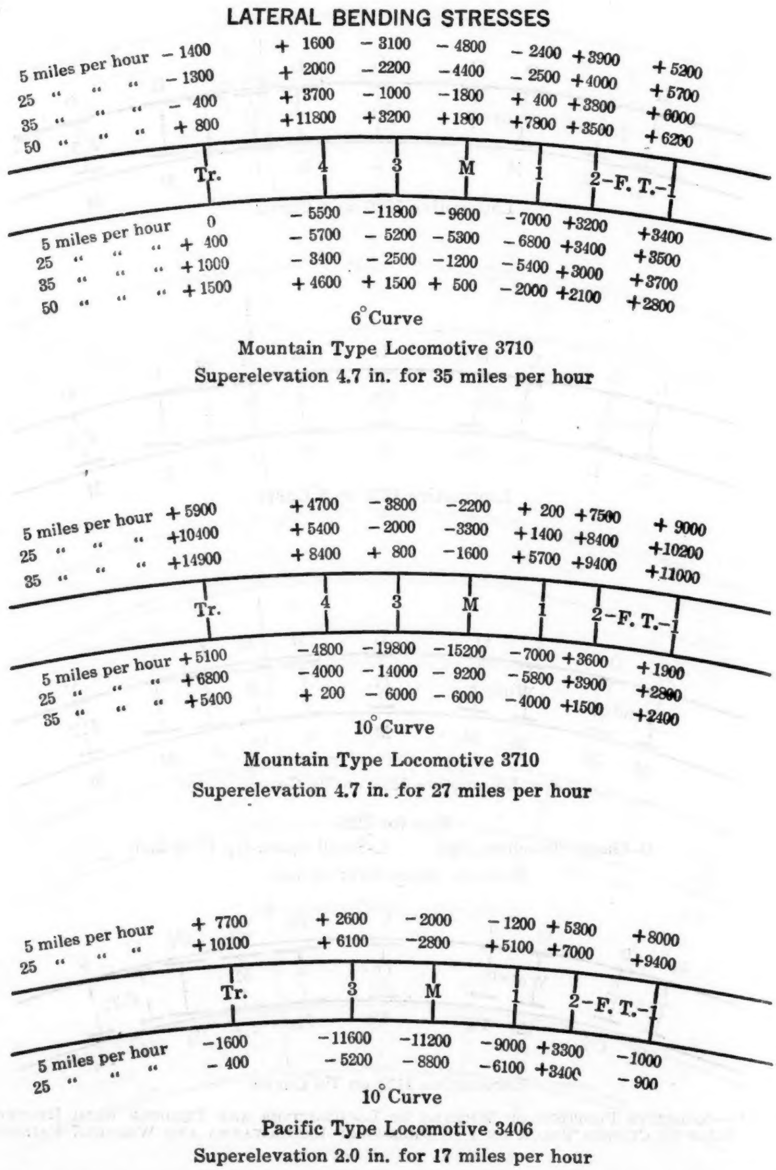


FIG. 75.—LATERAL BENDING STRESSES IN BASE OF RAILS OF CURVED TRACK, MOUNTAIN AND PACIFIC TYPE LOCOMOTIVES OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

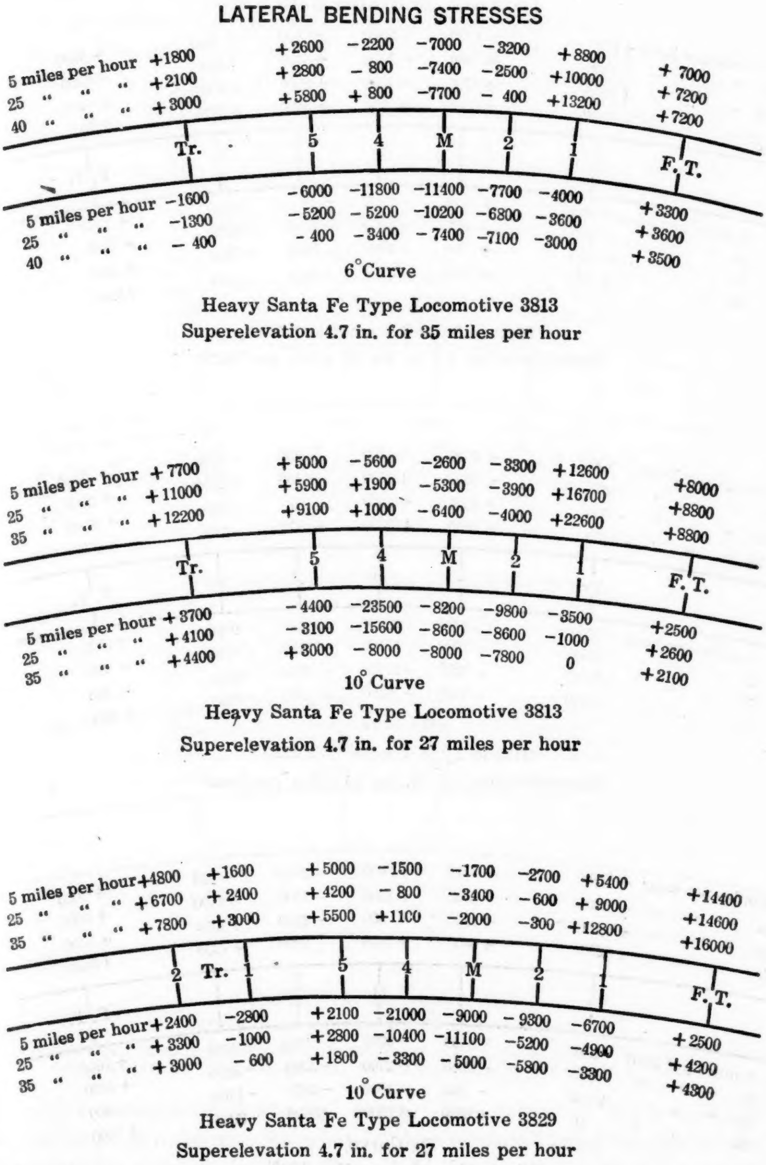


FIG. 76.—LATERAL BENDING STRESSES IN BASE OF RAILS OF CURVED TRACK, HEAVY SANTA FE TYPE LOCOMOTIVES OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

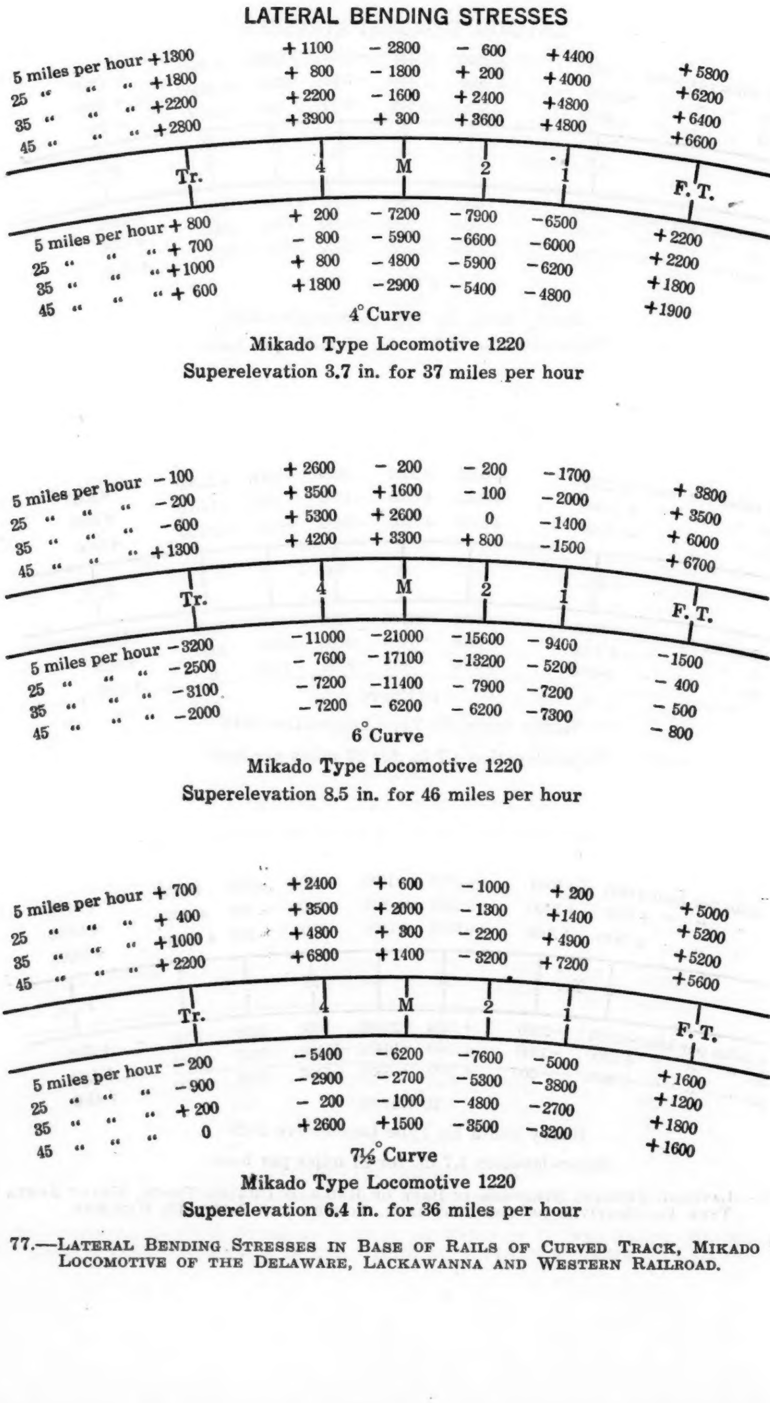


FIG. 77.—LATERAL BENDING STRESSES IN BASE OF RAILS OF CURVED TRACK, MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

that the flanges of the outer wheel of the front truck always have an important part in changing the direction of the locomotive.

In the locomotive having two-wheel front trucks, the lateral bending of the outer rail at the outer front driver is positive at all speeds, with the exception of the Mikado type on the 6° curve, where the super-elevation is 8.5 in. With the locomotives having four-wheel leading trucks, the bending at the outer front driver is generally negative at the low speed, becoming positive at a higher speed, with the exception that it remains negative in the case of the

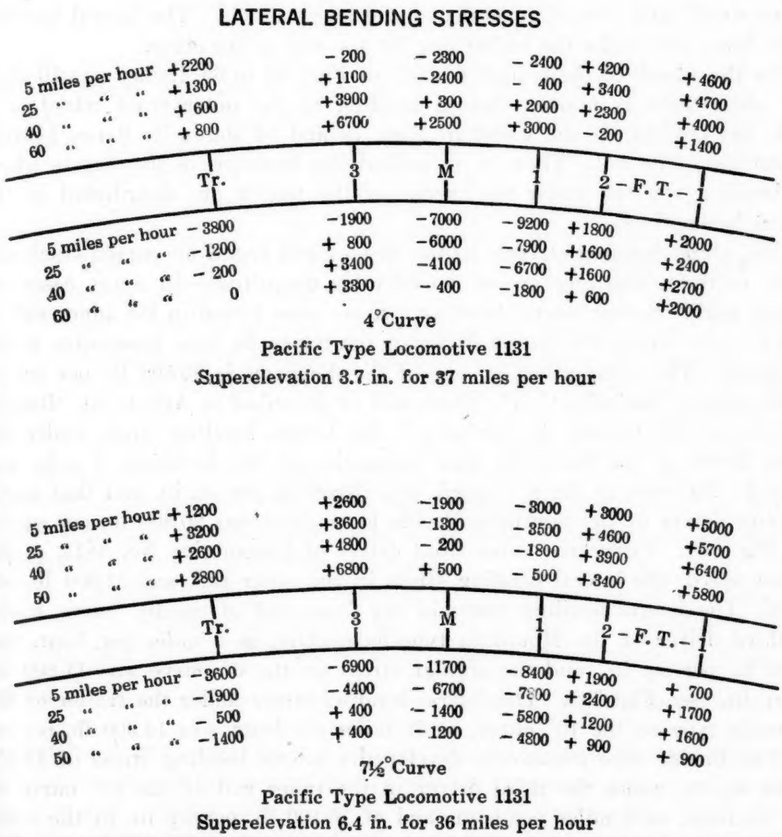


FIG. 78.—LATERAL BENDING STRESSES IN BASE OF RAILS OF CURVED TRACK, PACIFIC TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

Pacific type locomotive on the 7½° curve. The nature of the bending of the outer rail is in agreement with what is to be expected from the position of the outer front driver given in Figs. 73 and 74.

The outer rear driver gives a positive lateral bending in the outer rail (outward thrust on the rail) at all speeds, the one exception being the Pacific type locomotive on the 4° curve at a speed of 5 miles per hour.

At low speeds, all the other drivers generally give negative bending in both inner and outer rail, tending to straighten the rail. The principal ex-

ception is that the bending moment under the inner fifth driver of the Santa Fe type locomotive is sometimes positive.

An increase of speed results in an increase of lateral bending in the outer rail, decreasing the value of the lateral bending stress if the bending is negative and increasing the stress if it is positive.

An increase of speed results in a decrease in the lateral bending in the inner rail, the numerical value of the lateral stress decreasing when the bending moment is negative and increasing when it is positive.

The trailer has an outward thrust on the outer rail in every case at the higher speeds and almost generally at the lower speeds. The lateral bending of the inner rail under the trailer may be one way or the other.

For the wheels of the tender, a study of Figs. 42 to 63, inclusive, will show that when there is positive lateral bending at the outer front wheel of a truck, the position of the wheel in Figs. 73 and 74 shows its flange bearing against the outer rail. There is no uniformity, however, in the way in which the bending stresses under the trucks of the tender are distributed in the various locomotives.

The lateral bending stresses in the base of rail found on curved track and shown in these diagrams are of considerable magnitude—in many cases extremely high. Severe lateral bending stresses were found in the inner rail of the 10° curve under the fourth driver of the Santa Fe type locomotive at the low speed. The value given on one of the diagrams is 23 500 lb. per sq. in. In the tests at Bealville, Calif., which will be described in Article 20, "Results of Tests on 10° Curves in California", the lateral bending stress under the fourth driver of the Santa Fe type locomotive of the Atchison, Topeka and Santa Fe Railway, at the low speed, was 25 800 lb. per sq. in. and that under the same driver of the Southern Pacific locomotive was 20 300 lb. per sq. in. (see Fig. 96). Under the outer front driver of Locomotive No. 3813, at the highest speed, the lateral bending stress in the outer rail was 22 600 lb. per sq. in. The lateral bending stress in the inner rail of the 10° curve, under the third driver of the Mountain type locomotive, at 5 miles per hour, was 19 800 lb. per sq. in., and the similar stress on the 6° curve was 11 800 lb. per sq. in. (see Fig. 75). The lateral bending stress under the trailer of the Mountain type on the 10° curve, at 35 miles per hour, was 14 900 lb. per sq. in. The Pacific type locomotive developed a lateral bending stress of 11 600 lb. per sq. in. under the third driver in the inner rail of the 10° curve at Fort Madison, at 5 miles per hour, and of 10 100 lb. per sq. in. in the outer rail under the trailer, at a speed of 25 miles per hour (see Fig. 75). The Mikado type locomotive developed a lateral bending stress of 21 000 lb. per sq. in. in the base of the inner rail of the 6° curve under the third driver and 15 600 lb. per sq. in. under the second driver, these stresses being developed at slow speeds on track having a super-elevation of 8.5 in. (see Fig. 77). On the $7\frac{1}{2}°$ curve, with a super-elevation of 6.4 in., the corresponding lateral bending stresses were 6 200 and 7 600 lb. per sq. in., respectively (see Fig. 77). On the 4° curve, the corresponding lateral bending stresses were 7 200 and 7 900 lb. per sq. in. The Pacific type locomotive of the Delaware, Lack-

awanna and Western Railroad developed a lateral bending stress of 9 200 lb. per sq. in. in the inner rail under the first driver, on the 4° curve, and on the $7\frac{1}{2}$° curve, 11 700 lb. per sq. in. under the second driver; even on a 4° curve, it is seen that the lateral bending stress under some of the wheels is considerable in comparison with the vertical bending stress in the rail under these same wheels (see Fig. 78).

When the stress due to lateral bending is combined with that due to vertical bending, it will be seen that the resulting stress may be very great (see Figs. 42 to 67). This is the more marked because the high lateral bending stresses generally occur under wheels giving very high vertical bending stresses, much greater than those developed on straight track. Thus, for example, at the outside edge of the base of the inner rail of the 10° curve under the fourth driver of the Santa Fe type locomotive, at 5 miles per hour, the stress is the sum of 23 500 and 29 200, resulting in a stress of 52 700 lb. per sq. in. This value is the average of a large number of runs; not infrequently stresses several thousand pounds greater than this were found, indeed, one of 75 000 lb. per sq. in. was recorded. It may be added that the value of the lateral bending stresses under many of the wheels ranged from 40 to 100% of the vertical bending stress under the same wheel.

The lateral bending stresses observed at points between wheels are of measurable magnitude. Their values bear somewhat the same relation to the stresses under the wheels as that found with the vertical bending stresses on straight track. In general, the direction of the bending at points between wheels is opposite in character to that at the wheels, positive bending if that at the wheels is negative and negative bending if the other is positive. This inward and outward bending corresponds to the positive and negative bending moments found ordinarily at and between wheels for vertical load alone. The torsional stresses developed have not been analyzed.

16.—Lateral Bending Moments.—The lateral resisting moment developed in the rails, which, of course, at any point is equal to the lateral bending moment, may be readily calculated from the observed lateral bending stress by the use of the lateral section modulus, $\frac{I}{c}$, of the rail. The variation in the lateral bending moment at and between wheels throughout the length of the locomotive and at the several speeds offers an interesting view of the lateral bending action of the rails of curved track as the load passes. Figs. 79 to 83, inclusive, show the lateral bending moment in the outer and inner rails for four types of locomotives on several curves of different degrees of curvature. As before, positive bending is taken to be that which increases the curvature of the rail, and negative bending that which tends to straighten the rail.

A study of these diagrams brings out interesting characteristics of the different locomotives. The Mountain type on the 6° curve (Fig. 79) has much the same characteristics as it has on the 10° curve, although on the 6° curve, except at low speed, the lateral bending moments are small with the exception of the outer rail under the fourth driver. Except at the speed of 50 miles per hour, the principal turning action is given by the wheels of the front truck; on

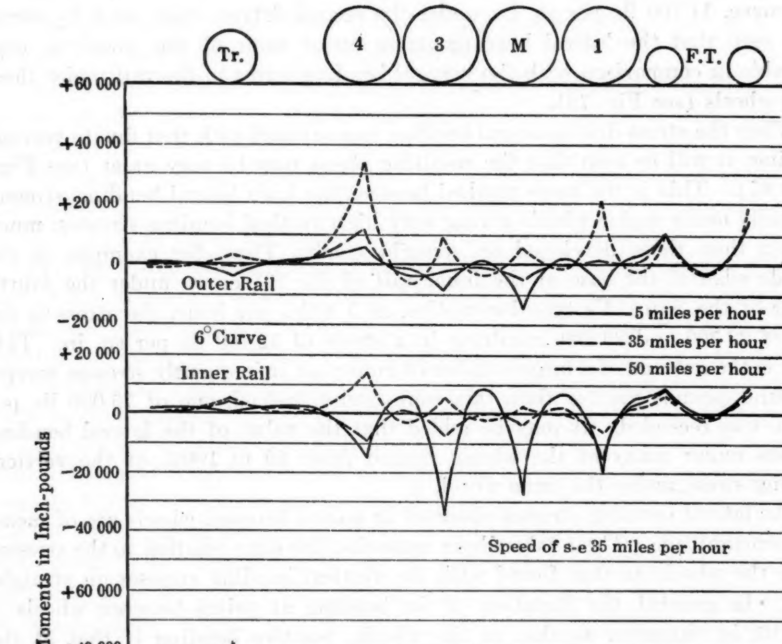


FIG. 79.—LATERAL BENDING MOMENTS IN OUTER AND INNER RAILS OF CURVED TRACK WITH MOUNTAIN TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

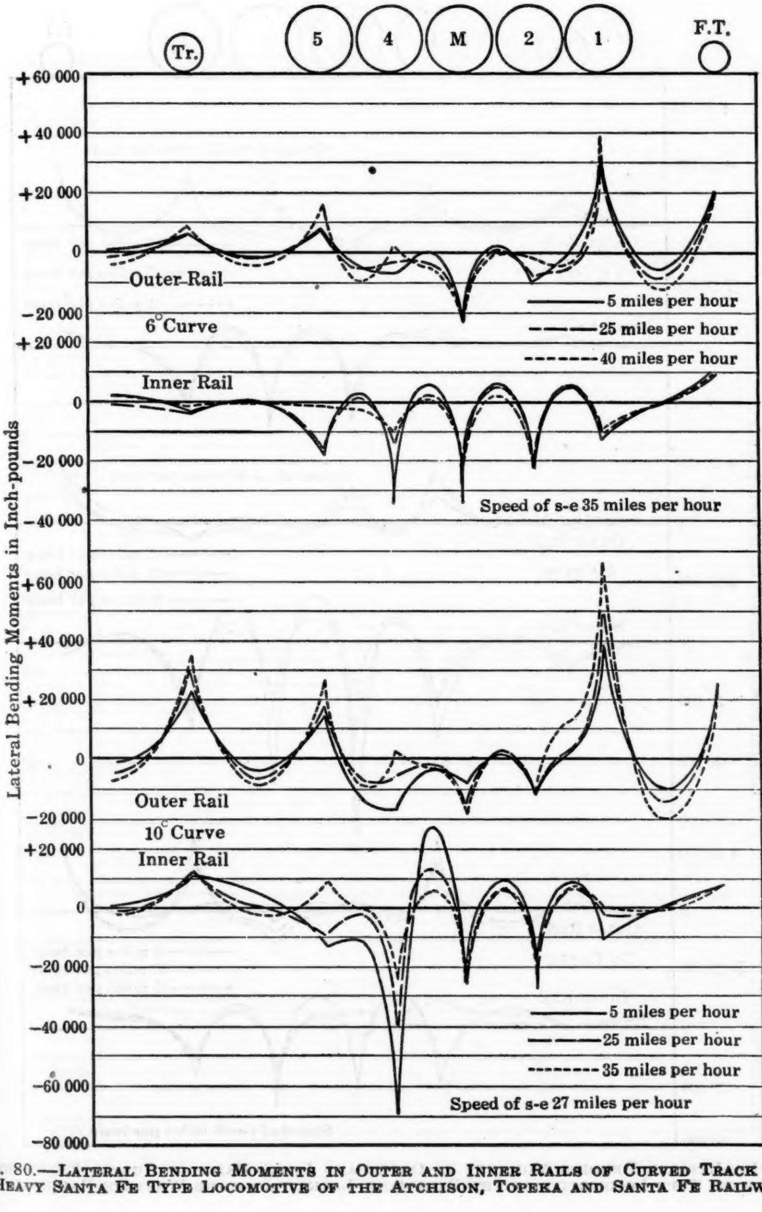


FIG. 80.—LATERAL BENDING MOMENTS IN OUTER AND INNER RAILS OF CURVED TRACK WITH HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

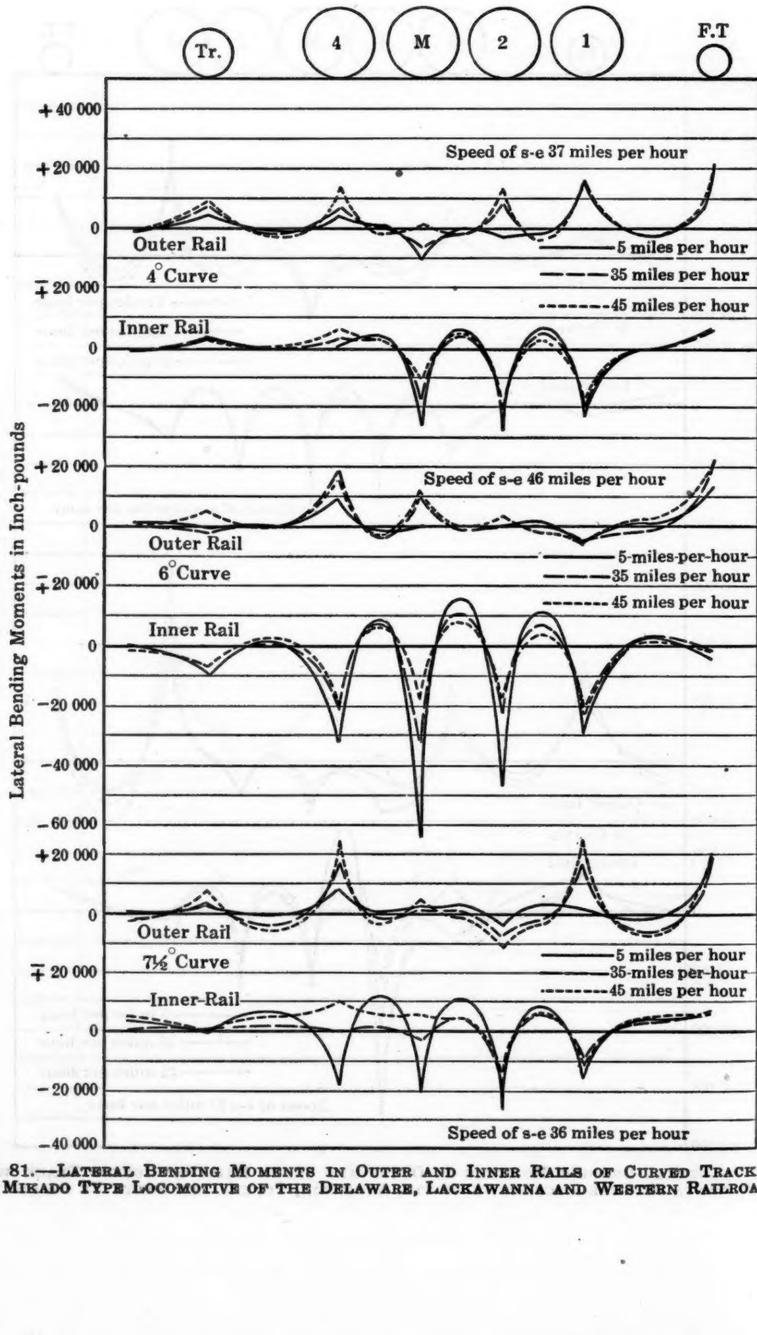


FIG. 81.—LATERAL BENDING MOMENTS IN OUTER AND INNER RAILS OF CURVED TRACK WITH MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

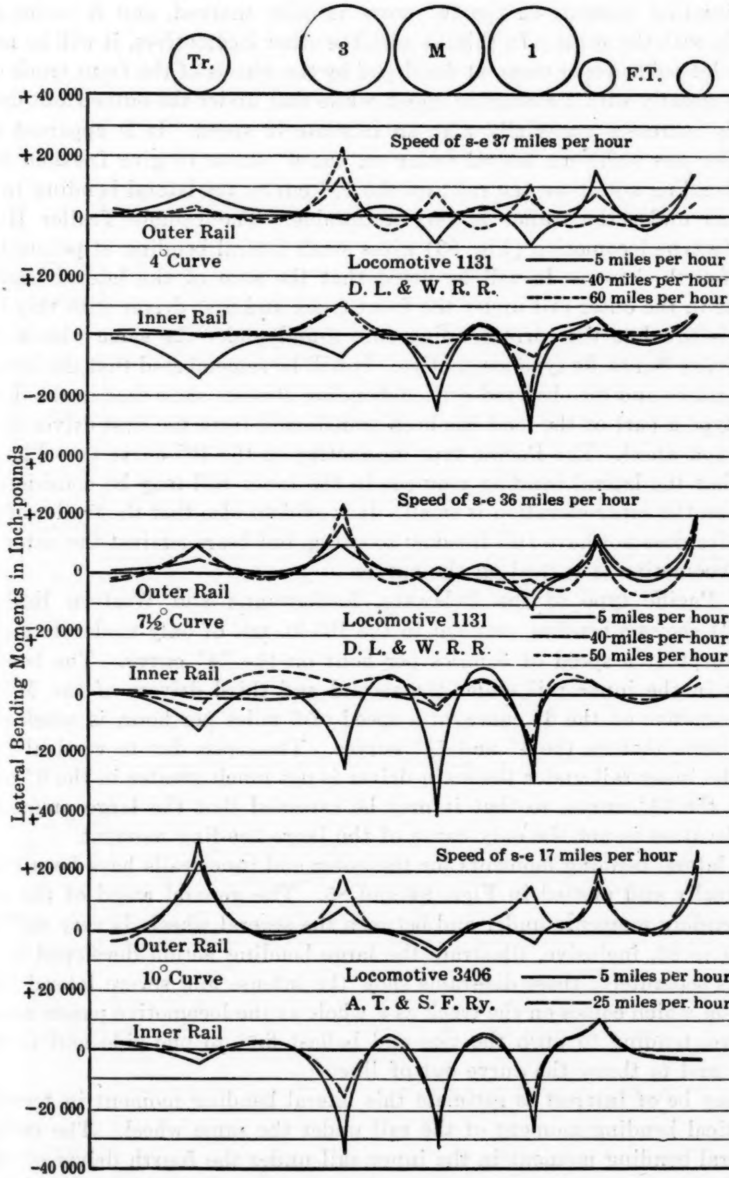


FIG. 82.—LATERAL BENDING MOMENTS IN OUTER AND INNER RAILS OF CURVED TRACK WITH PACIFIC TYPE LOCOMOTIVES.

both curves at the high speed, the front outer driver also participates in the turning action. With the Santa Fe type locomotive (Fig. 80), the magnitude of the bending moment on the 10° curve is quite marked, and it varies considerably with the speed. In this, as with the other locomotives, it will be noted that the lateral bending moment developed by the wheels of the front truck does not vary greatly with a change in speed, while that under the outer front driver generally increases materially with an increase in speed. It is apparent that the trailer has sufficient lateral swing on the 6° curve to give freedom from lateral bending action on the rail; on the 10° curve, the lateral bending in the outer rail under the trailer is very noticeable. The Double Trailer Heavy Santa Fe type locomotive (Fig. 83) gives small lateral bending at points back of the fourth driver. It will be noted that the sum of the lateral bending moments in the outer rail under the front truck and first driver with this locomotive is equal to the corresponding sum found under the same wheels with the ordinary Santa Fe type locomotive. It will be remembered that the locomotive diagrams and the observed vertical bending stresses show that in the double trailer type a part of the load has been transferred from the first driver to the front truck wheel. The Pacific type locomotive on the 10° curve (see Fig. 82) shows that the lateral bending moment in the inner rail may be considerable, even when the super-elevation is small. It is evident also that the trailer of this locomotive does not have full freedom to swing, but bears against the outer rail as the locomotive is turned on the curve.

The Pacific type of the Delaware, Lackawanna and Western Railroad (Fig. 82) shows a bending moment in the 105-lb. rail of only moderate magnitude, except at a speed of 5 miles per hour on the 7½° curve. The bending moment in the inner rail under the second and third drivers of the Mikado type locomotive on the 6° curve, at a speed of 5 miles per hour, is much more marked than that on the 4° and 7½° curves. The stress due to vertical bending in the inner rail under the main driver is not much greater in the 6° curve than in the 7½° curve, so that it may be expected that the large amount of super-elevation is not the only cause of the large bending moment.

The lateral bending moments for the outer and inner rails have been added algebraically and plotted in Figs. 84 and 85. The general trend of the combined bending moments under and between the several wheels is very striking. Figs. 79 to 83, inclusive, illustrate the large bending action developed in the two rails separately; these diagrams show the intense and severe lateral bending action which comes on the track as a whole as the locomotive passes around the curve, tending to push the ties and ballast first to one side and then to another and to throw the curve out of line.

It may be of interest to estimate this lateral bending moment in terms of the vertical bending moment of the rail under the same wheel. The ratio of the lateral bending moment in the inner rail under the fourth driver of three Santa Fe type locomotives (two of them belonging to the Atchison, Topeka and Santa Fe Railway and one to the Southern Pacific Company) to the vertical bending moments developed at the same time averages 0.16 at the lowest speed on the 10° curves. It should be recalled too that the vertical bending stress under this driver was far greater than the normal and that the pressure of the

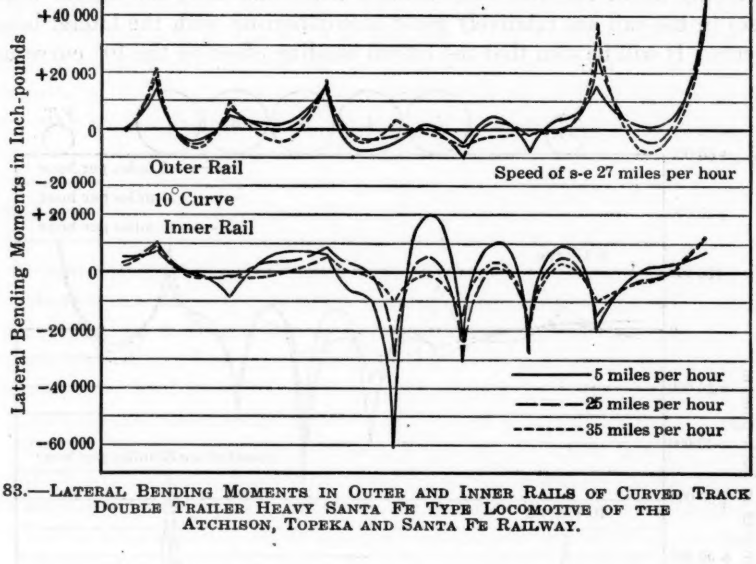


FIG. 83.—LATERAL BENDING MOMENTS IN OUTER AND INNER RAILS OF CURVED TRACK WITH DOUBLE TRAILER HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

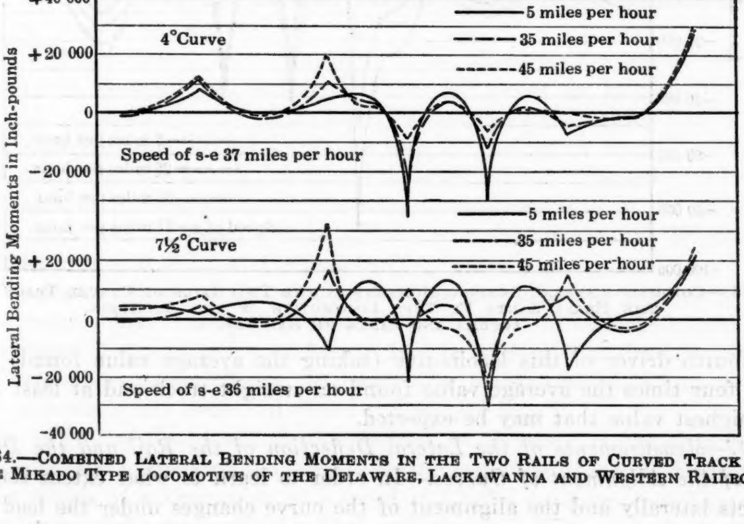


FIG. 84.—COMBINED LATERAL BENDING MOMENTS IN THE TWO RAILS OF CURVED TRACK WITH THE MIKADO TYPE LOCOMOTIVE OF THE DELAWARE, LACKAWANNA AND WESTERN RAILROAD.

driver on the rail must have been nearly twice the normal load. The ratio of the lateral bending moment under the same wheels to the vertical bending moment found generally on straight track averaged 0.04, although values as great as 0.14 were found. As the section modulus of the rail about a vertical axis is only about one-fifth that about a horizontal axis, the lateral bending stresses in the rail are relatively great in comparison with the lateral bending moments. It will be seen that the lateral bending effect on the 10° curve under

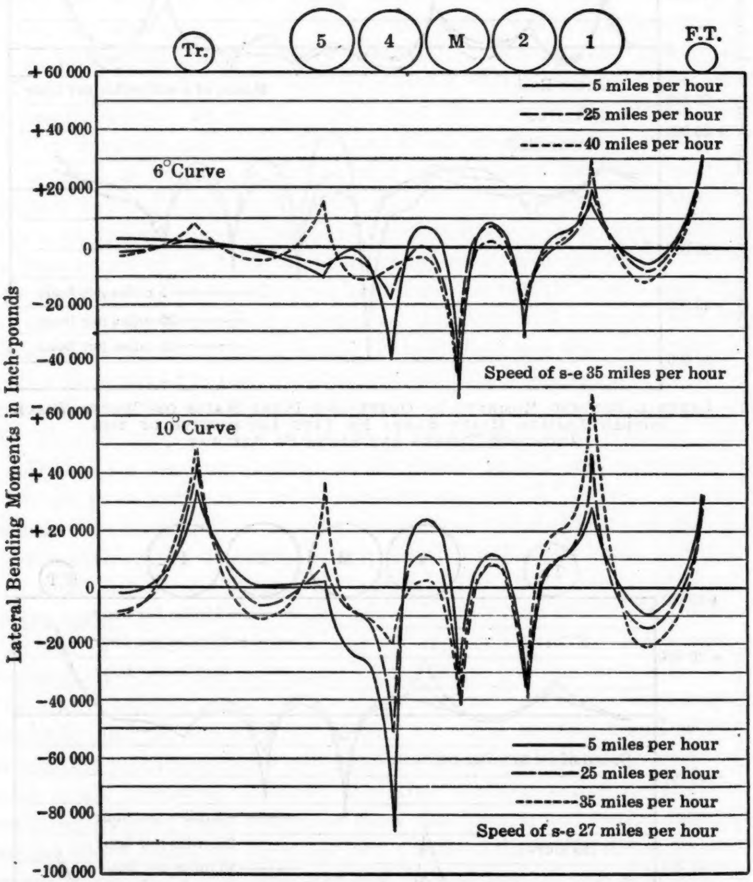


FIG. 85.—COMBINED LATERAL BENDING MOMENTS IN THE TWO RAILS OF CURVED TRACK WITH THE HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

the fourth driver of this locomotive (taking the average value found) is at least four times the average value found on straight track and at least twice the highest value that may be expected.

17.—Measurements of the Lateral Deflection of the Rail and the Distortion of the Alignment of Curves.—In order to learn to what extent the rail deflects laterally and the alignment of the curve changes under the load of a locomotive and to see the conditions under which lateral bending moments of

considerable magnitude are developed, some measurements were made on both 6° and 10° curves. An instrument was devised with which the middle ordinate of a 6-ft. chord along the rail was measured. The two bearing ends of the instrument were placed in punch marks in the side of the head of the rail and the plunger of an Ames dial at the middle of the instrument was also placed in contact with the side of the head of the rail. The measurements were taken at every 3 ft. of length of rail on both inner and outer rail, thus overlapping one another. A set of readings (zero reading) with no load on the track was taken; the locomotive was then run on and a second set of readings taken, check readings also being generally made. The tests were not as complete as was desired; they show however, the nature of the movement of the rails. More tests of this nature should give information of value.

Fig. 86 shows the alignment of the track with the locomotive standing on the 6° and 10° curves, at Ribera, with reference to the original alignment. The values recorded on the diagram represent the distance the rail is deflected from its original position, the measurement being given in inches. As the measurements were taken on the head of the rail a part of the distortion of the alignment may be due to tilting of the rail on the tie. Necessarily, in enlarging the small dimensions sufficiently to show the new position of the rails, the lines on the diagram appear distorted and also the axles are not shown as parallel to each other. Attention is called to the position of the rail joints; their smaller lateral stiffness evidently contributes to the lateral deflection.

It is seen that with the Mountain type locomotive on the 10° curve the inner rail deflects more than ½ in. from its original position and that the gauge of the track is increased from 4 ft. 8½ in. to as much as 4 ft. 9½ in. The outward deflection of the outer rail at the front truck wheel and first driver is large, 0.35 in. at the first driver. The greatest deflection is that of the inner rail under the third driver, 0.54 in. The changes from positive to negative bending between wheel points are evident.

With the Mountain type locomotive on the 6° curve, the lateral deflection of both rails is much less, that of the inner rail under the third driver being only 0.13 in., and the gauge of the track was increased only about ¼ in.

With the Double Trailer Santa Fe type locomotive on the 10° curve, the inner rail under the fourth driver was deflected 0.7 in. The outer rail under the fourth driver was deflected inwardly of the track 0.14 in., so the gauge of the track was increased 0.56 in. There was also an outward deflection of the outer rail of 0.42 in. at the first trailing wheel.

The general shape of the alignment which the rails take and the position of the many points of contraflexure are in general accord with the lateral bending moment diagrams given in Article 16. It is plain that the alignment of a curve changes materially as the locomotive passes around it and that the track as a whole has large and varied stresses put into it.

18.—Effect of Speed and Counterbalance on Curves.—It has already been found that the average of the stresses in the two rails of curved track under all the wheels of a locomotive, at a speed of 5 miles per hour, found by dividing the sum of the stresses under all the wheels of the locomotive for both rails by the number of wheels, in general agrees closely with the average of the corre-

sponding stresses under the same wheels on straight track. If the average stress under all the wheels for the two rails of any curve is found for each of the speeds of any test and compared with the corresponding average stress on straight track, it will be seen that the average stress on the curved track is generally no higher and sometimes lower than that on straight track, or, at

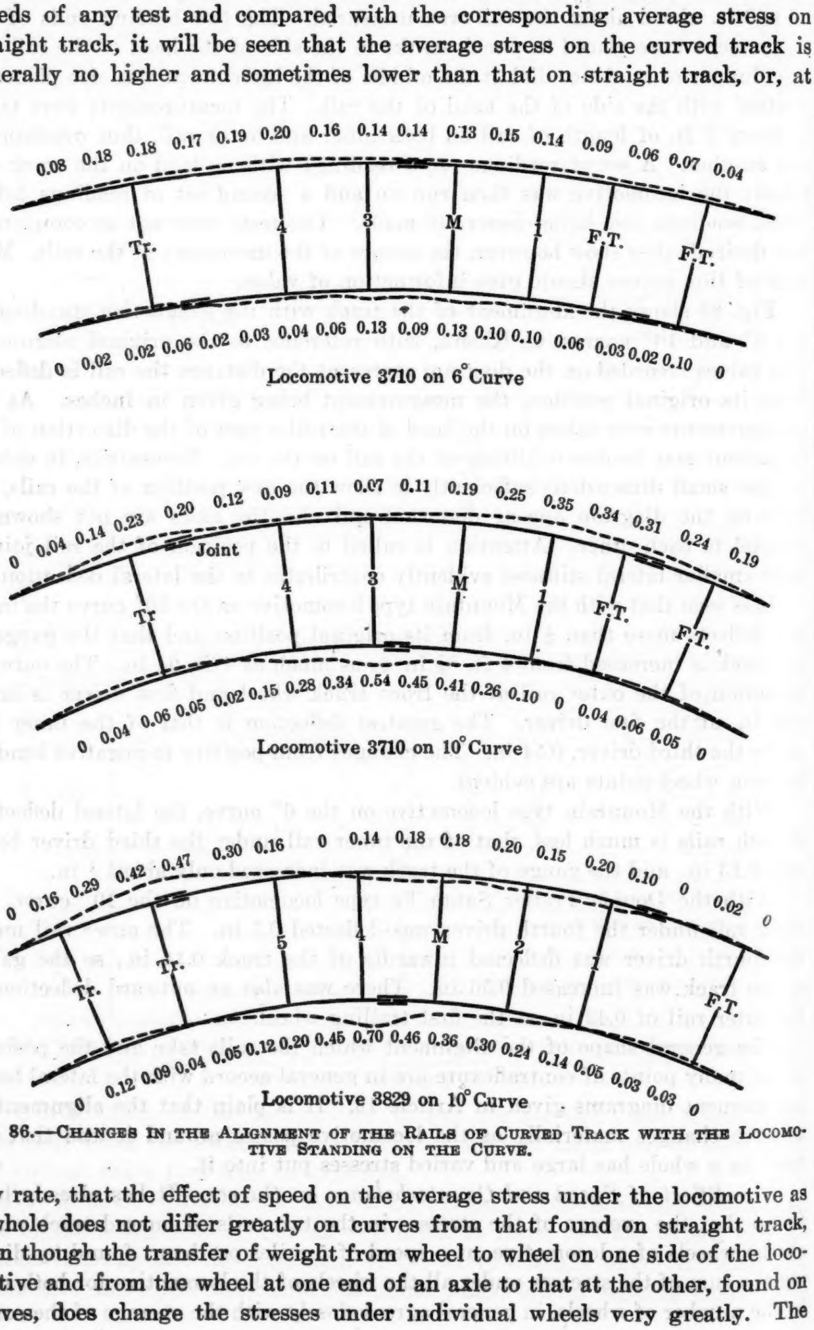


FIG. 86.—CHANGES IN THE ALIGNMENT OF THE RAILS OF CURVED TRACK WITH THE LOCOMOTIVE STANDING ON THE CURVE.

any rate, that the effect of speed on the average stress under the locomotive as a whole does not differ greatly on curves from that found on straight track, even though the transfer of weight from wheel to wheel on one side of the locomotive and from the wheel at one end of an axle to that at the other, found on curves, does change the stresses under individual wheels very greatly. The

lateral bending stresses in rails on curves, of course, are not involved in the foregoing statement.

The effect of counterbalance on the stresses in rail on curved track is much more variable than that found on straight track. In a few cases well defined counterbalance curves could be drawn through the plotted points, but generally no line seemed representative of the effect of counterbalance. The points are scattered throughout a large vertical range, and there is much more variation in the results than is found on straight track. In estimating the stress that will include the effect of counterbalance, the best that can be done is to take the average stress throughout the revolution of the driver and then allow for a very much greater variation in the stress above and below this line than would be done for straight track. One interesting result of the study of the data is that, under a number of the wheels, the stresses at the outside edge of the rail showed marked effect of counterbalance, whereas those at the inside edge show almost no counterbalance effect.

The effect of speed on the division of the load of the locomotive between the two rails of the curve is quite another matter. In most cases, the total load on the outer rail transmitted by all the wheels of one side of the locomotive bears the numerical relation to the total load on the inner rail that would be given by the analytical calculation of the effect of transverse inclination of track and centrifugal force at the given speed. This means that at slow speeds the load on the inner rail is considerably greater than the normal load, the vertical bending stresses in the inner rail with the Mikado type locomotive running at a speed of 5 miles per hour being found to be as much as 37% greater with the super-elevation of 8.5 in. on the 6° curve of the Delaware, Lackawanna and Western Railroad than on straight track. At and near the speed of super-elevation, in most of the tests on curved track, the vertical bending stresses in the two rails do not differ much from each other. It may be noted that analysis shows that the speed may be increased considerably beyond the speed of super-elevation before the load on the outer rail would become equal to that imposed on the inner rail at low speeds. Although the ratio varies with the degree of curve and the super-elevation used, it may be said that for the track used in the tests the speed may be increased 30 to 40% beyond that of super-elevation before the load on the outer rail may be expected to equal that found on the inner rail at low speeds. The foregoing discussion refers to the sum of the loads under all the wheels; the distribution of load among the several drivers may be quite unequal, the vertical bending stresses in the rail under one driver of one type of locomotive being as much as double what might be expected in the case of the 10° curve and 50% more on the 6° curve.

The lateral bending stresses developed in the rails also vary with the speed. The lateral bending stresses in the inner rails are very great at the slow speeds, especially at the driver in front of the rear driver, and sometimes the one in front of this, in the case of the locomotives having eight and ten drivers. For medium speeds, say, up to two-thirds of the speed of super-elevation, the lateral bending stress under the rear intermediate driver continues to be of considerable magnitude. For the higher speeds, the lateral bending stresses under

these wheels decrease markedly and at the speed of super-elevation the highest lateral bending stress in the inner rail may not differ greatly from the highest stress found in the outer rail. The greatest lateral bending stress in the outer rail under a driver is found at the outer front driver in those locomotives in which the wheel of the leading truck does not assume the principal part in changing the direction of the locomotive. With an increase in speed, this lateral bending stress increases. As the stresses in the outer rail under the wheels of the front truck do not increase with an increase in speed, it is evident that the greater effort to change the direction of the locomotive at the higher speeds is taken by the flange of this first outer driver.

The effect of speed on the stress at the two edges of the base of rail (combined vertical bending stress and lateral bending stress) is well shown in Figs. 64, 65, 66, and 67. A marked decrease in the stress at the outside edge of the base of the inner rail under the driver in front of the rear driver with increase of speed is very noticeable. The increase of stress in both edges of the outer rail under the companion driver is also apparent. It may be noted also that the stresses at the four edges of the two rails under the wheels of the tender generally approach uniformity of magnitude at the speed of super-elevation.

19.—Effect of Degree of Curve and Super-Elevation.—It has been seen that both the vertical bending stress and the lateral bending stress have wide ranges in value in the two rails and for the individual wheels of the several locomotives used. It may be expected that these differences will vary with the degree of curve and the super-elevation of the outer rail, although it may not be possible to distinguish between the effects of the two. In comparing the action of the locomotives, it will be convenient to refer to the values given in Figs. 69 to 72 and Figs. 75 to 78.

With the Santa Fe type locomotive on the 10° curve, at 5 miles per hour, the vertical bending stress of 29 200 lb. per sq. in. in the inner rail under the fourth driver may be contrasted with the stress of 19 400 lb. per sq. in. on the 6° curve having the same super-elevation, 4.7 in., the corresponding stress on straight track being about 12 000 lb. per sq. in. It is evident that vertical bending stress under this driver, which must be considered an excessive stress for both curves, increases with the increase in curvature, although the curves have the same super-elevation. At the speed corresponding to the super-elevation, the stress under this wheel in both curves decreased nearly to what might be expected under an even division of load among the drivers. The vertical bending stress in the inner rail of the 10° curve under the first driver, at a speed of 5 miles per hour, is less than would be expected, and decreases with an increase of speed, while on the 6° curve it remains nearly constant for the three speeds. The vertical bending stress in the outer rail of the 10° curve under the first driver, at 5 miles per hour, is not much higher than that which would normally be expected. The high value of 27 000 lb. per sq. in., at 35 miles per hour, is, of course, at a speed well above that of super-elevation. The vertical bending stresses in the outer rail under the third and fourth drivers are small; that under the fourth driver, at 5 miles per hour, is very small, showing that the load transmitted by this driver is only a small proportion of its normal load; the driver opposite it on the inner rail takes most of the load. Even at the

highest speeds, the stresses in the outer rail of both curves under this driver are below normal values. It is evident that on both curves the distribution of the load among the drivers given by the equalizing system is markedly different from that on straight track. The lateral bending stress in the inner rail, at 5 miles per hour, is very great under the fourth driver, 23 500 lb. per sq. in. on the 10° curve and 11 800 lb. per sq. in. on the 6° curve, which are very severe stresses in both cases. Even at 25 miles per hour, the stress recorded for the 10° curve was 15 600 lb. per sq. in. At the highest speed, the lateral bending stresses in the inner rail become much smaller. The lateral bending stresses in the outer rail under the first driver, indicative of the participation of this driver in changing the direction of the locomotive, at a speed of 5 miles per hour, are 12 600 lb. per sq. in. on the 10° curve and 8 800 lb. per sq. in. on the 6° curve. These lateral bending stresses increase markedly from the low speed to the highest, becoming 22 600 lb. per sq. in. on the 10° curve, at 35 miles per hour, and 13 200 lb. per sq. in. on the 6° curve, at 40 miles per hour. Bearing in mind that the lateral bending stresses at the outer wheel of the front truck vary little with changes in speed, the results indicate that altogether a larger amount of lateral pressure is required to change the direction of the locomotive at the higher speeds than at the low speeds. The amount of the lateral pressure given by the front driver also increases somewhat with the degree of curve, although the influence of the curvature does not seem to be as great as that of speed.

With the Mountain type locomotive on the 10° curve, at 5 miles per hour, the greatest vertical bending stress in the inner rail (average stress) is under the third driver, 26 700 lb. per sq. in. On the 6° curve, the vertical bending stresses are high under the first, second, and third drivers, that under the third driver, 19 700 lb. per sq. in., being about the same as that under the other two. An increase of speed to that corresponding to the super-elevation brings the vertical bending stresses in the inner rail of two curves under the fourth drivers down to about the same average value as the others, although that under the third driver on the 10° curve, 20 600 lb. per sq. in., remains greater than the others. At speeds above the speed of super-elevation, the vertical bending stresses in the inner rail have decreased materially and are much the same on both curves for all the drivers. The vertical bending stresses in the outer rail, particularly under the second and third drivers, are somewhat smaller on the 10° curve than on the 6° curve, these wheels being on the same axle as those giving very high vertical bending stresses in the inner rail. The stresses normally to be expected are not found until a speed higher than that of super-elevation is reached. The lateral bending stress in the inner rail is greatest under the third driver at 5 miles per hour, 19 800 lb. per sq. in. on the 10° curve and 11 800 lb. per sq. in. on the 6° curve. These values are roughly proportional to the degree of curve. On the 6° curve, a small value is found at the speed of super-elevation, but on the 10° curve, even at 25 miles per hour, the lateral bending stress is 14 000 lb. per sq. in., although the stress decreases rapidly with further increases of speed. In the outer rail, due probably to this locomotive having a four-wheel leading truck, the first

driver does not participate in changing the direction of the locomotive, except at the higher speeds. At 50 miles per hour, on the 6° curve, the outward lateral bending stress under the first driver becomes 7 800 lb. per sq. in. It is worth noting also that the outward bending stress in the outer rail under the fourth driver, on the 6° curve, reaches 11 800 lb. per sq. in., at a speed of 50 miles per hour. At the lower speeds, it is evident that there is a transfer of load from the outer to the inner rail on both curves, but the change is the greater on the 10° curve. It is apparent that the lateral bending stress in the inner rail for low speeds is a function of the curvature, the super-elevation being the same.

With the Mikado type locomotive on the Delaware, Lackawanna and Western Railroad, the even distribution of vertical bending stresses in the inner rail under all the drivers, at a speed of 5 miles per hour, is very apparent for all three curves, but the stresses differ on the three curves, and it may be a question as to what extent these differences in stress are due to super-elevation and to what extent they are due to curvature. The vertical bending stresses under the four drivers average about 13 000 lb. per sq. in., on the 4° curve (3.7 in. super-elevation, 105-lb. rail), 18 000 lb. per sq. in., on the 7½° curve (6.4 in. super-elevation, 105-lb. rail), and 22 400 lb. per sq. in., on the 6° curve (8.5 in. super-elevation, 92-lb. frictionless rail). It may be noted that this uniformity of stress under all the drivers is quite different from that found with the locomotives on the track of the Atchison, Topeka and Santa Fe Railway. The vertical bending stresses in the outer rail have small values under all the drivers, particularly under the main driver. They do not reach the values found in the inner rail until a speed well above that corresponding to super-elevation has been reached. The lateral bending stresses in the inner rail are much more marked in the 6° curve and are somewhat higher in the 4° curve than in the 7½° curve. It is not clear that the super-elevation is the cause of this variation. It is worth noting that, although this locomotive has a two-wheel leading truck, the lateral bending stresses in the outer rail under the first driver, at a speed of 5 miles per hour, show that this driver does not participate in changing the direction of the locomotive, except on the 4° curve. On the 6° curve, which has the frictionless rail, the lateral bending moments in the outer rail at the first driver are negative for all speeds.

With the Pacific type locomotive of the Atchison, Topeka and Santa Fe Railway, on the 10° curve at Fort Madison, Iowa, the super-elevation being only 2 in., the vertical bending stress in the inner rail under the three drivers, at a speed of 5 miles per hour, is nearly double that in the outer rail. This goes to show that in this case the curvature and not the super-elevation is the main cause of shifting the load of the locomotive to the inner rail. With the Pacific type locomotive of the Delaware, Lackawanna and Western Railroad, the shift of load to the inner rail is somewhat greater on the 7½° curve than on the 4° curve; both the curvature and the super-elevation may be responsible for this. Considering the difference in the rail sections, the lateral bending stress in the inner rail, at 5 miles per hour, is really greater on the

$7\frac{1}{2}°$ curve than that found on the 10° curve of the Atchison, Topeka and Santa Fe Railway; it is lower still on the 4° curve. The outer rail shows no turning action by the front driver on any of the three curves, at a speed of 5 miles per hour, most of the change of direction evidently being accomplished by the wheels of the front truck. At the higher speeds, the front driver participates in the turning action in the case of the 4° curve and the 10° curve, but not the $7\frac{1}{2}°$ curve.

To sum up the foregoing: On all the curves and for locomotives having eight and ten drivers, at the lower speeds the vertical bending stress is markedly greater in the inner rail under the next to the last driver than that in either rail under any other driver; for locomotives of the Pacific type the stress in the inner rail is greater, but to a somewhat less degree, under all three drivers than that in the outer rail. The vertical bending stress in the outer rail is correspondingly small under the companion driver of the one giving the high stresses in the inner rail. These effects are especially noticeable at the low speeds; they continue at moderate speeds, and generally disappear at or above the speed of super-elevation. Although part of the increased value of the vertical bending stress in the inner rail is due to the transfer of load to the lower rail by reason of the transverse inclination of the track, the excess over what may be expected on straight track is greater than may be accounted for by the super-elevation, and, frequently, this discrepancy is unexpectedly great. It appears then that the equalizing system acts differently on curves than on straight track and that much more load is concentrated on one inner driver, the outer driver being relieved of a corresponding amount of load. This phenomenon was found on all the curves. Although this lack of even distribution of stresses under the drivers of one side was not present in the tests with the Pacific type locomotive, yet the vertical bending stresses in the inner rail with this locomotive are higher than may be explained by the transverse inclination of the track. It will be seen that on all the curves an increase of speed to one at or above the speed corresponding to the super-elevation results in vertical bending stresses under the different wheels of the two rails more nearly what may be expected when the effect of transverse inclination and centrifugal force are considered.

The lateral bending stress in the inner rail under the driver giving the large vertical bending stresses and also under the one ahead of it is quite marked at the lower speeds on all the curves. Although the value of the stress is considerably greater on the 10° curve, its magnitude is of considerable importance on the 6° and 4° curves.

The lateral bending stress in the outer rail under the first driver, resulting from the flange of this driver assisting in the change of direction of the locomotive, when found at the low speed, seems not to increase much with increased curvature of the track. As has already been noted, this lateral bending stress does increase with an increase in speed.

20.—Results of Tests on 10° Curves in California.—The data of tests made by the Atchison, Topeka and Santa Fe Railway and the Southern Pacific Company, in April, 1922, on the tracks of the two railways, as they relate

to the purposes of this report, have been made available to the Committee. These tests were conducted on a 10° curve of the Southern Pacific Company, at Bealville, Calif., and on a 10° curve of the Atchison, Topeka and Santa Fe Railway at Cajon, Calif. The locomotives were the Heavy Santa Fe type of the Atchison, Topeka and Santa Fe Railway and the Heavy Santa Fe type of the Southern Pacific Company, both being equipped with oil burners. The rail at Bealville was 90-lb. A. R. A.-A. section; that at Cajon was 90-lb. S. F. section. As already noted, the properties of these rails are nearly identical. At Bealville, there were 5 in. of new rock ballast on a thick mixed rock ballast foundation. At Cajon, there were 10 in. of gravel ballast. The former gave the stiffer track.

The purpose of the tests was to determine the action and rigidity of the locomotives used in the tests. On the tests made at Cajon, a flangeless tire was substituted for the flanged wheel ordinarily used for the fourth driver, the third driver being flangeless as usual. As used at the first part of the tests, the bearing part of the tread of the fourth driver was cylindrical. Later, a groove to approximate the conditions after wear was machined into the tread. Speeds of 10 and 18 miles per hour were used at both locations. The runs were made on 2.2% compensated grade, net grades of 1.8% on the Atchison, Topeka and Santa Fe Railway and of 2.0% on the Southern Pacific Company. Runs were made in two directions—up grade and down grade. The up-grade tests were made with the locomotive working steam and pulling from 9 to 12 loaded cars, the load pulled being altogether approximately 500 tons. The draw-bar pull, as measured by the dynamometer car placed immediately behind the tender, recorded about 30 000 lb. on the various runs. On the down-grade tests, the locomotives ran light and without working steam, that is, coasting.

Figs. 87 to 94, inclusive, show the average stresses for the several runs at the inside edge and outside edge of both inner and outer rails of the 10° curves at Bealville and Cajon, and at the two speeds. Figs. 95 and 96 give the values of the vertical bending stress and the lateral bending stress at Bealville and Figs. 97 and 98 the values at Cajon. Attention should be called to the fact that, in the down-grade tests at Bealville, with both locomotives, it was raining and misting all day and the rails were continually wet; this seems to have had an effect on the stresses developed under one of the locomotives and to a less extent on the other.

The stresses in the rails with the locomotive of the Atchison, Topeka and Santa Fe Railway, at Bealville, are, in general, very much the same in magnitude and character as those found with a locomotive of the same class on the 10° curve at Ribera, N. Mex., except that, on account of the locomotive used in California being equipped with oil burners, the weight on the trailers was only about three-fourths of that of the locomotive used in New Mexico, and the stresses under the trailers were correspondingly smaller. The stresses with the locomotive of the Southern Pacific Company differed in some important respects from those under that of the Atchison, Topeka and Santa Fe Railway, as did those with the locomotive with modified drivers used at Cajon.

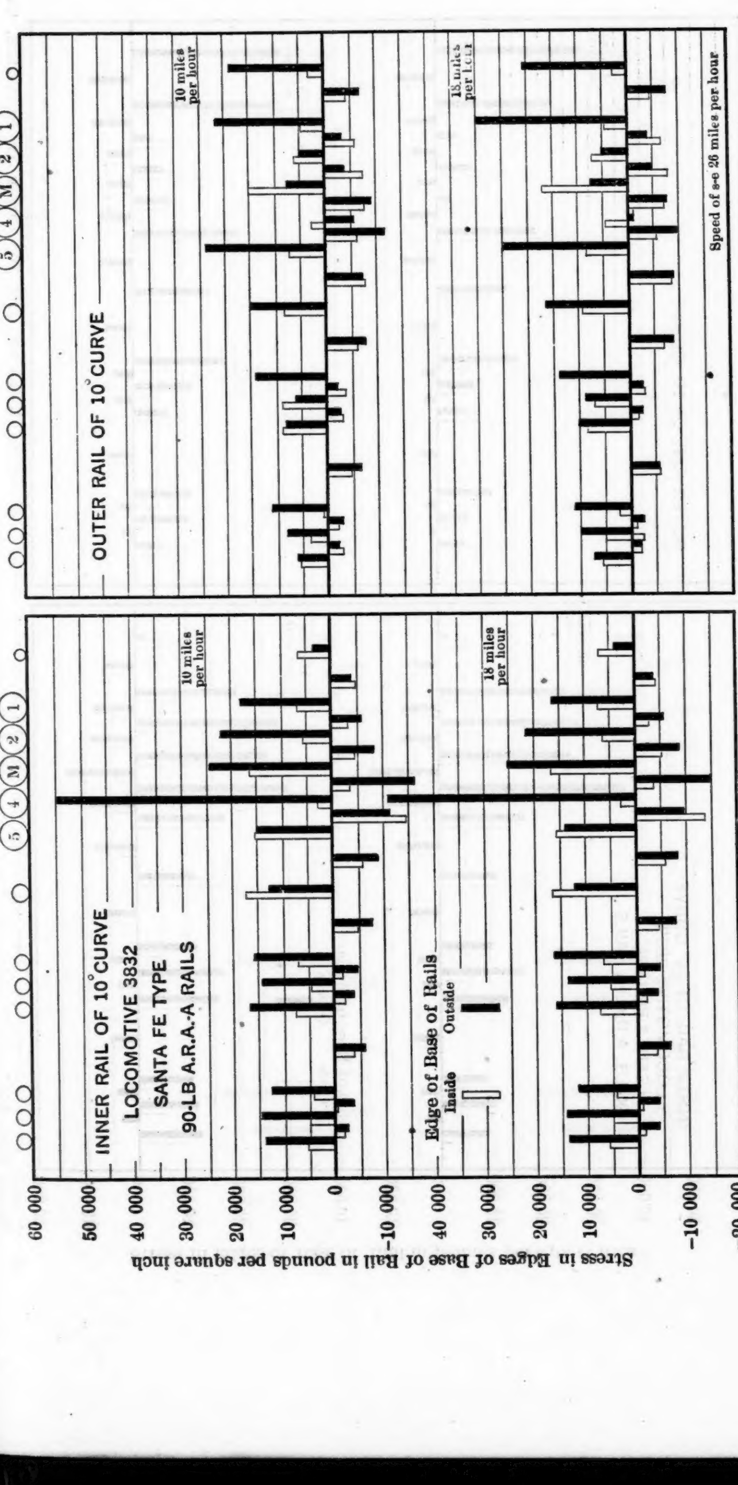


FIG. 37.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 10° CURVE AT BEALVILLE, CALIF., SERIES 5500–5503, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY, PULLING 540 TONS UP-GRADE.

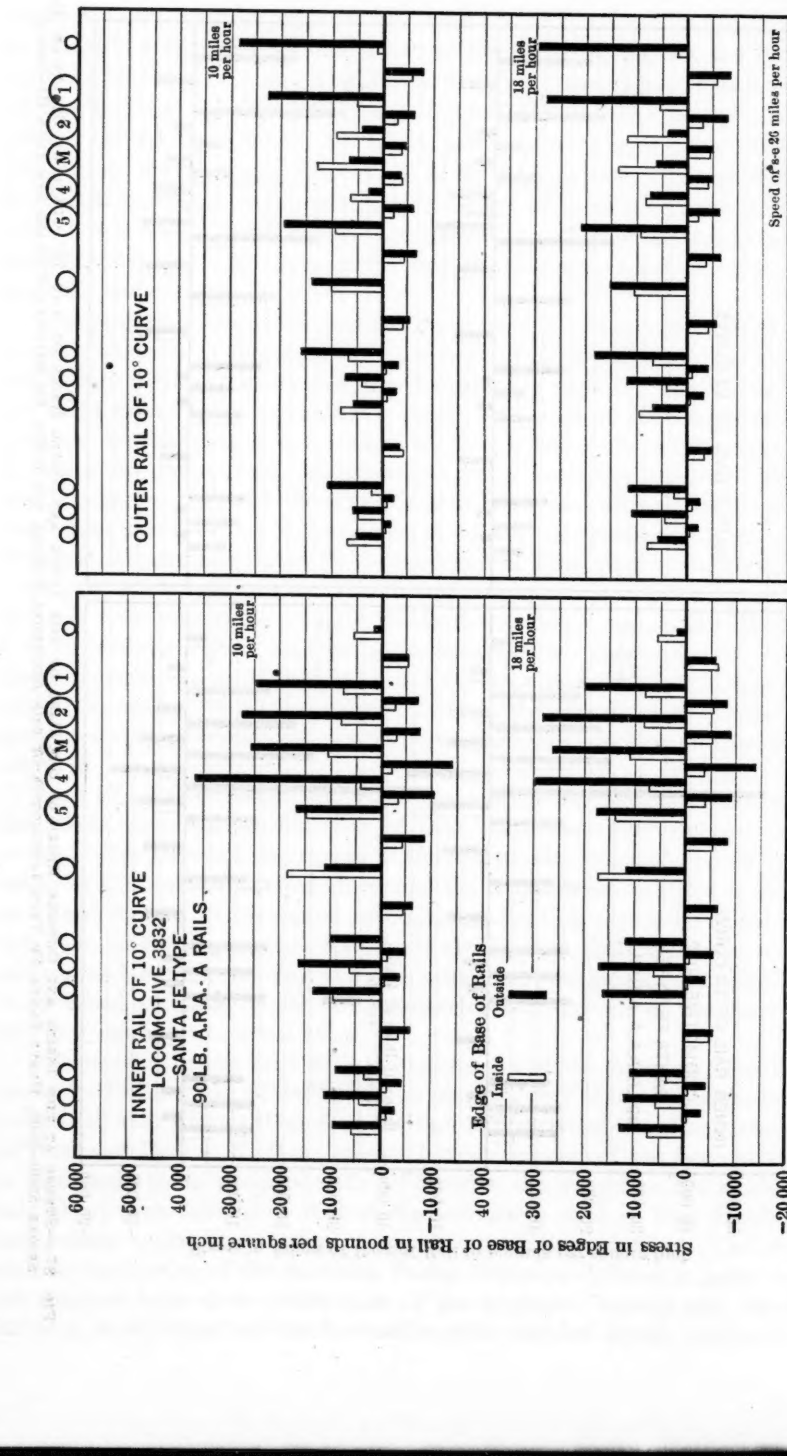


FIG. 88.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 10° CURVE AT BEALVILLE, CALIF., SERIES 5504–5507, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY. DOWN-GRADE, LIGHT.

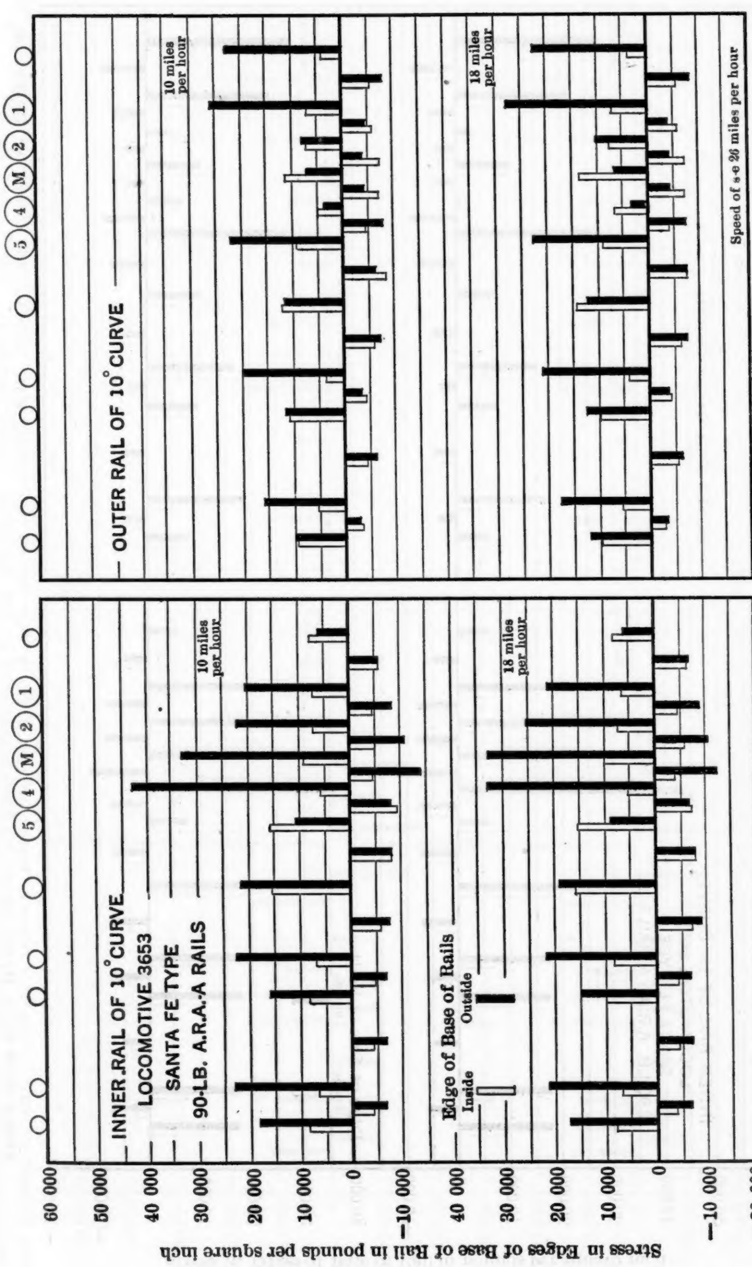


FIG. 89.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 10° CURVE AT BEALVILLE, CALIF., SERIES 5513–5516, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE SOUTHERN PACIFIC COMPANY, PULLING 540 TONS UP-GRADE.

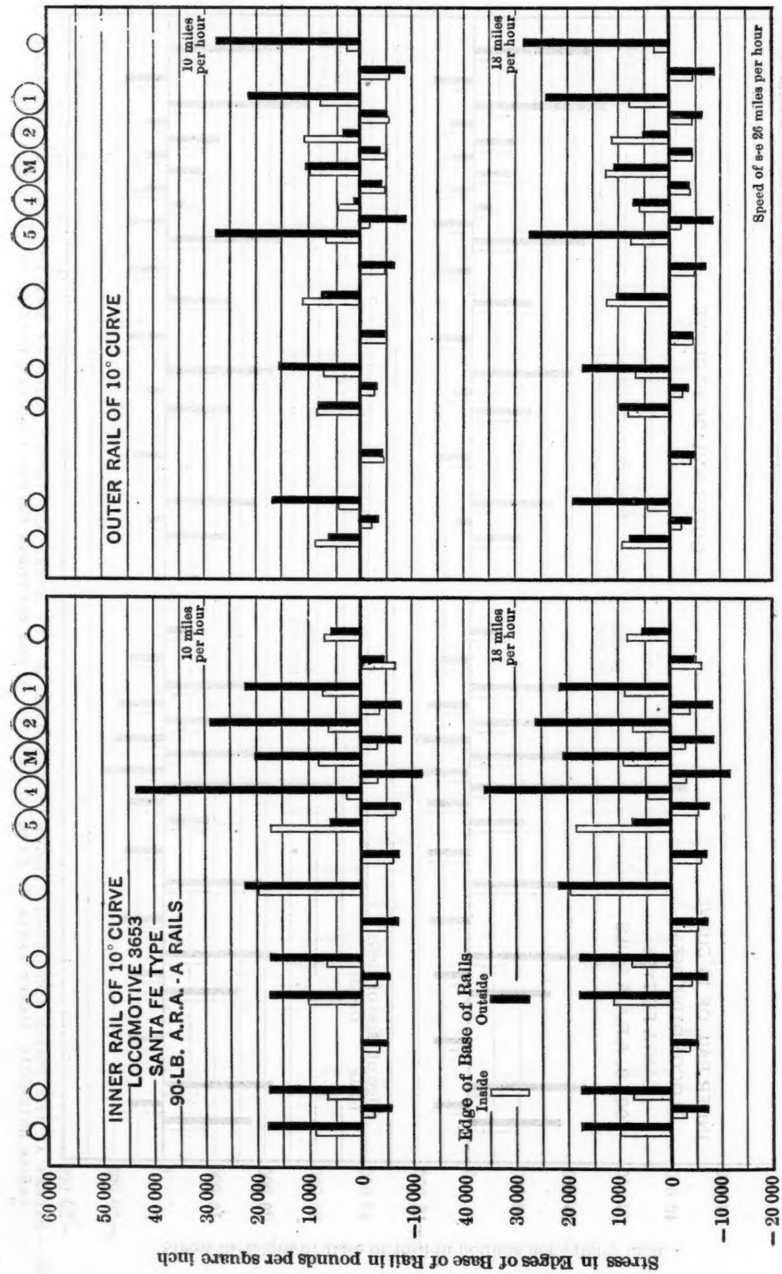


FIG. 90.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAIL OF THE 10° CURVE AT BEALVILLE, CALIF., SERIES 5508–5512, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE SOUTHERN PACIFIC COMPANY. DOWN-GRADE, LIGHT.

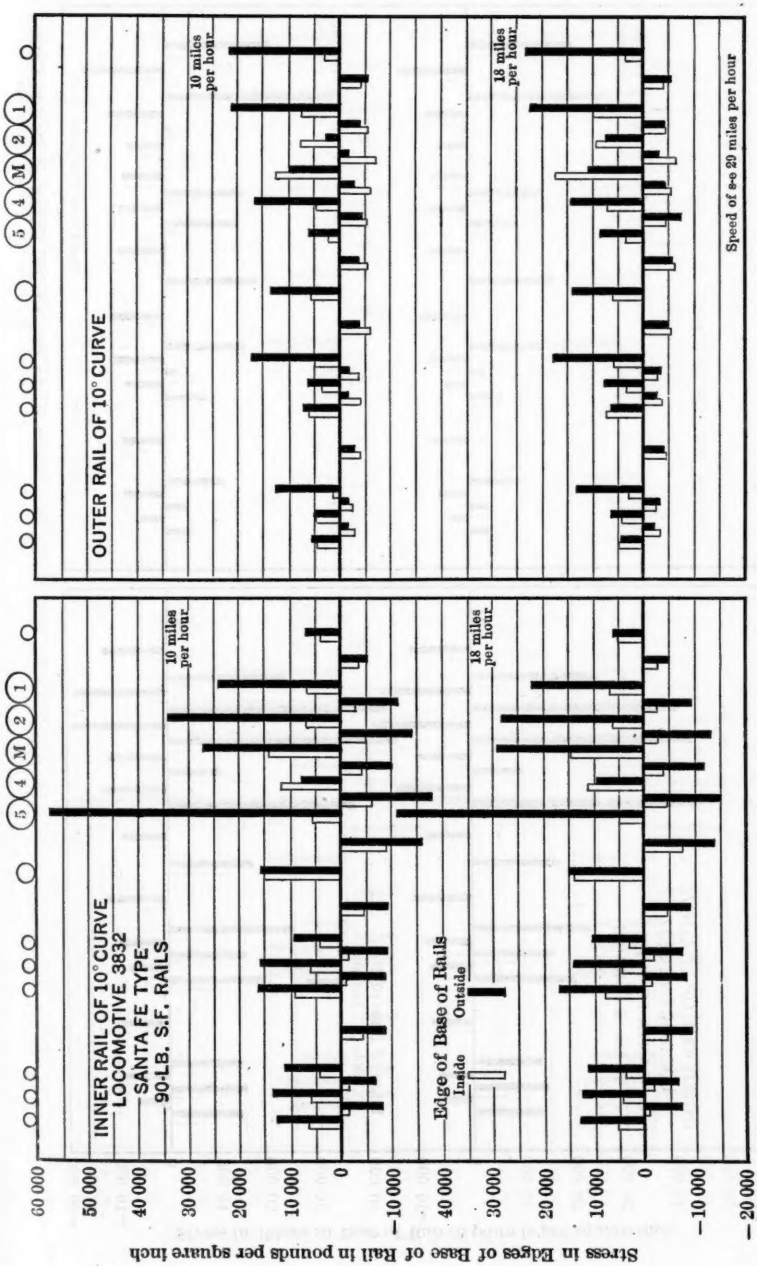


FIG. 91.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 10° CURVE AT CAJON, CALIF., SERIES 5523–5526, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY, WITH FOURTH DRIVER FLANGELESS AND TREAD CYLINDRICAL. PULLING 500 TONS UP-GRADE.

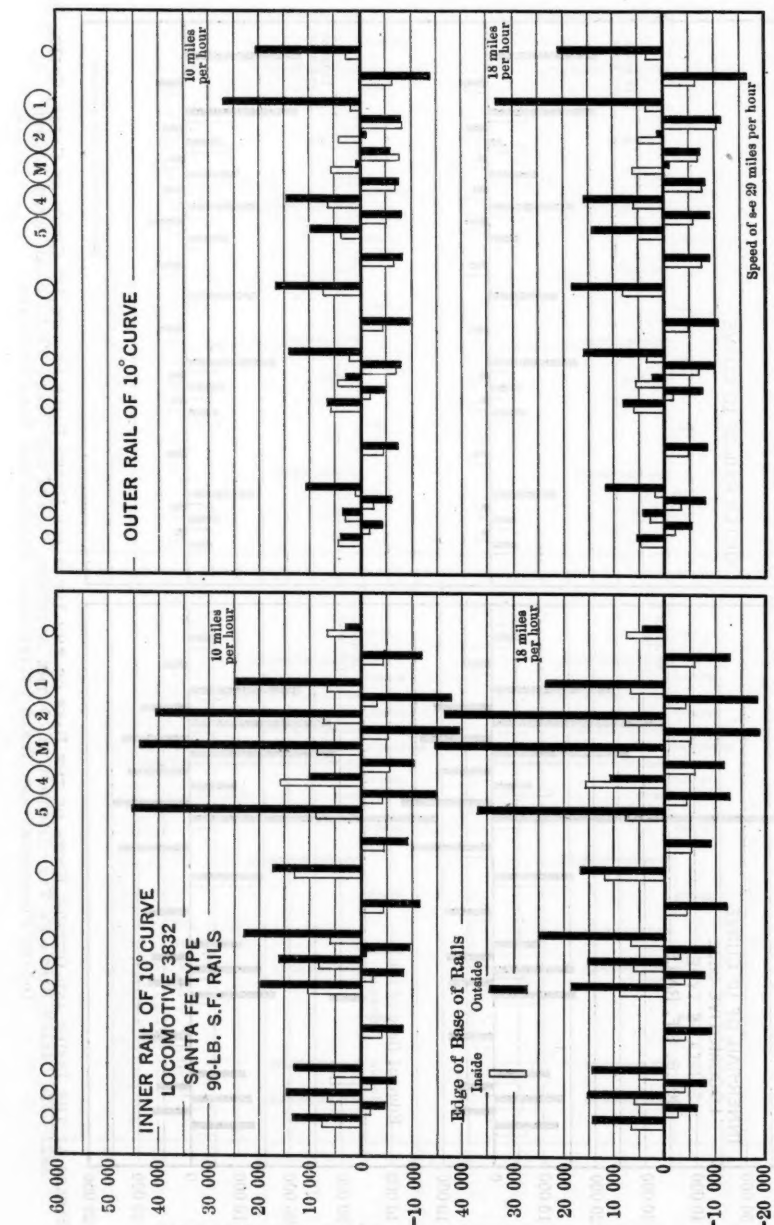


FIG. 92.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 10° CURVE AT CAJON, CALIF., SERIES 5519–5522, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY, WITH FOURTH DRIVER FLANGELESS AND TREAD CYLINDRICAL. DOWN-GRADE, LIGHT.

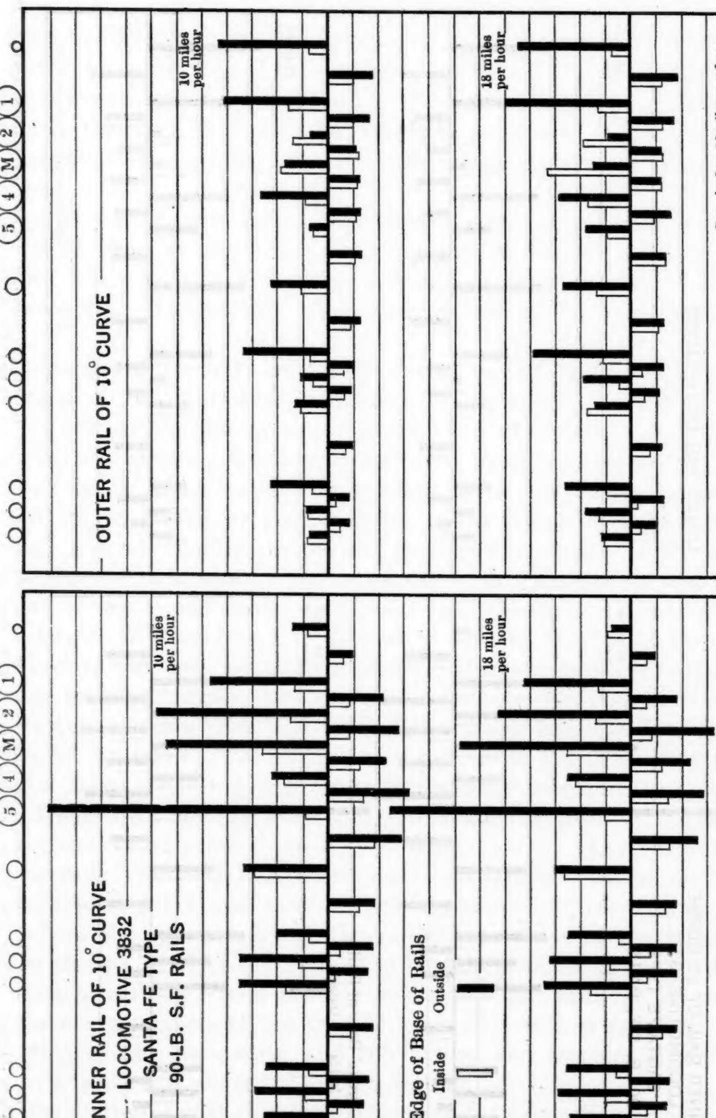


FIG. 93.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 10° CURVE AT CAJON, CALIF., SERIES 5527–5530, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY, WITH FOURTH DRIVER FLANGELESS AND TREAD GROOVED. PULLING 500 TONS UP-GRADE.

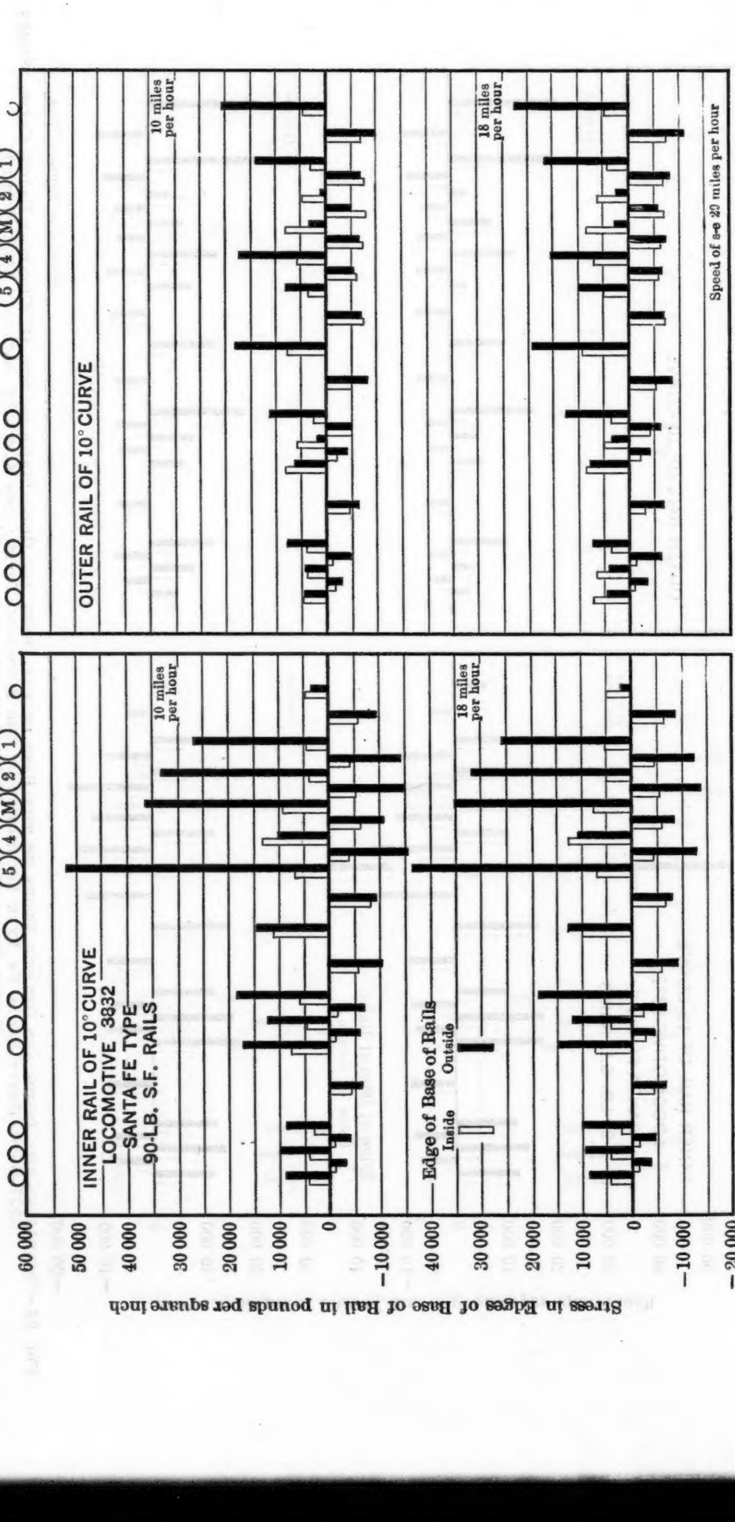


FIG. 94.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 10° CURVE AT CAJON, CALIF., SERIES 5531-5534, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY, WITH FOURTH DRIVER FLANGELESS AND TREAD GROOVED. DOWN-GRADE, LIGHT.

Table 23 shows that loads at individual wheels calculated from the vertical bending stresses, at a speed of 10 miles per hour, are excessively high, namely, 50 000, 52 000, and 60 000 lb. These high loads do not necessarily occur under the same drivers, the variations seemingly being dependent on the presence or absence of flanges. It will be seen, from Fig. 95 and Fig. 97, that the vertical bending stresses under the inner driver that gives the high vertical bending stress and, therefore, transmits the high load, are nearly as great at 18 miles per hour as at 10 miles per hour, the speed of super-elevation being 26 miles per hour.

Figs. 99 and 100 give the average stress for the several runs at the inside and outside edges of both inner and outer rail of the 10° curve at Bealville when the locomotives were backing down grade at 10 miles per hour. The rails were dry. The records of the locomotives of the two companies are given.

The results of the tests on the 10° curves in California will be discussed with those of the other tests in Articles 21, 22, and 23, on "Type of Locomotive", "Effect of Pulling and Coasting and of Condition of Rail", and "Tests with Locomotive Backing over Curved Track", respectively.

21.—Type of Locomotive.—On straight track the stresses developed in the rail are controlled by such matters as the wheel loads and the wheel spacing. Lateral bending stresses are developed by reason of the coning of the wheels, the variations in the movement of the locomotive, and by irregularities in track conditions. Variations in the design of locomotives, such as the length of wheel-base, the number of drivers, the use of two-wheel or four-wheel trucks, may be made without bringing unduly high stresses into the rail, provided proper care is used in making the design. On curved track, other considerations will be found to enter into the development of stresses in the track. The change of direction of the locomotive in going around a curve is effected by pressure between the flanges of the outer wheels of the front truck and the outer rail and frequently, also, by the outer first driver, resulting in a lateral bending of the outer rail. An unexpected effect is the greatly increased load transmitted to the inner rail by one or more of the drivers at low and medium speeds and a corresponding decrease in the load on the opposite driver, the conditions producing excessive vertical bending stresses in the inner rail. The lateral spreading action on the inner rail develops marked lateral bending stresses in that rail. In all these matters, the characteristics of the type of locomotive will be found to influence the action of the locomotive and the nature and amount of the stresses developed in the rail under the various wheels.

In the matter of changing the direction of the locomotive, it seems evident from the tests that the four-wheel truck of the Pacific and Mountain types presents advantages over the two-wheel truck of the Santa Fe and Mikado types. With the four-wheel leading truck used, the loads on the wheels are such as to give moderate vertical bending stresses. The lateral bending stresses in the outer rail under the outer wheels of the four-wheel truck on curves from 4° to 10° may be termed moderate. With the locomotives having

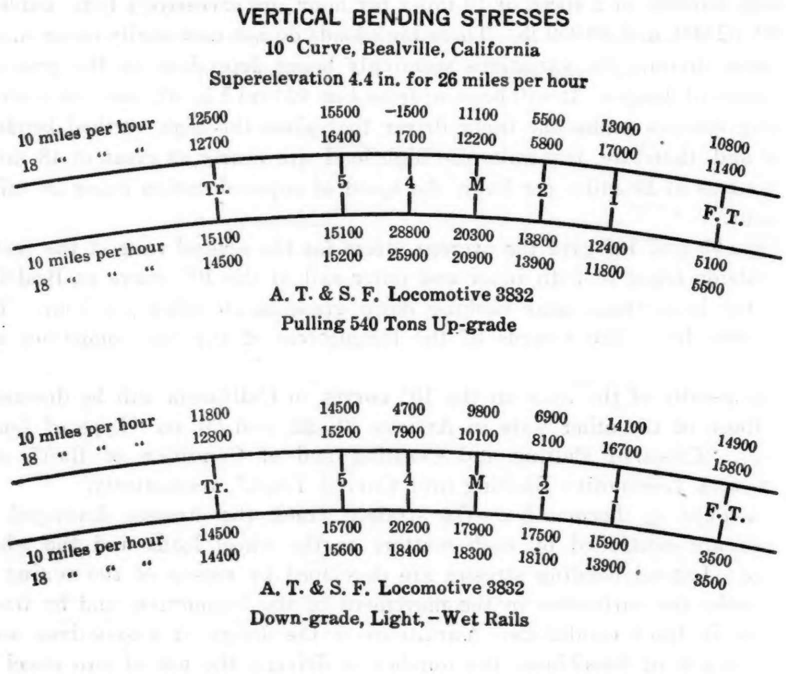


FIG. 95.—VERTICAL BENDING STRESSES IN BASE OF RAILS OF THE 10° CURVE AT BEALVILLE, CALIF., HEAVY SANTA FE TYPE LOCOMOTIVES OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY AND THE SOUTHERN PACIFIC COMPANY.

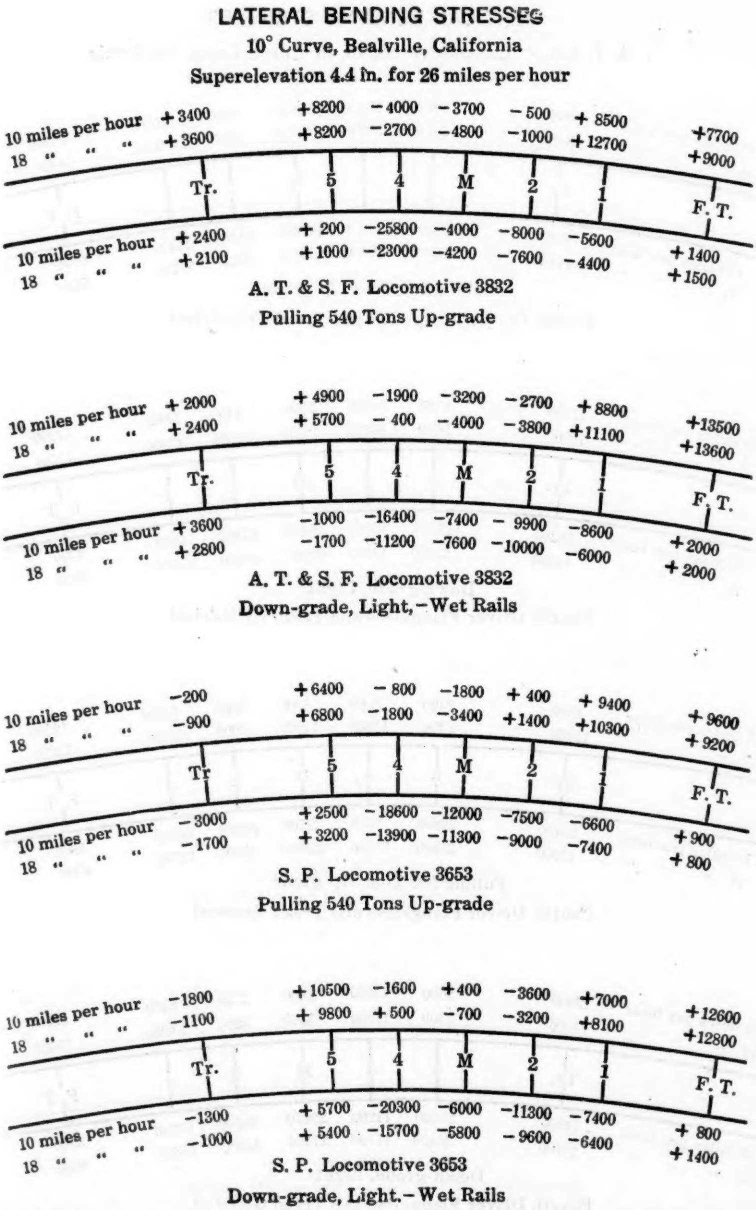


FIG. 96.—LATERAL BENDING STRESSES IN BASE OF RAILS OF THE 10° CURVE AT BEALVILLE, CALIF., HEAVY SANTA FE TYPE LOCOMOTIVES OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY AND THE SOUTHERN PACIFIC COMPANY.

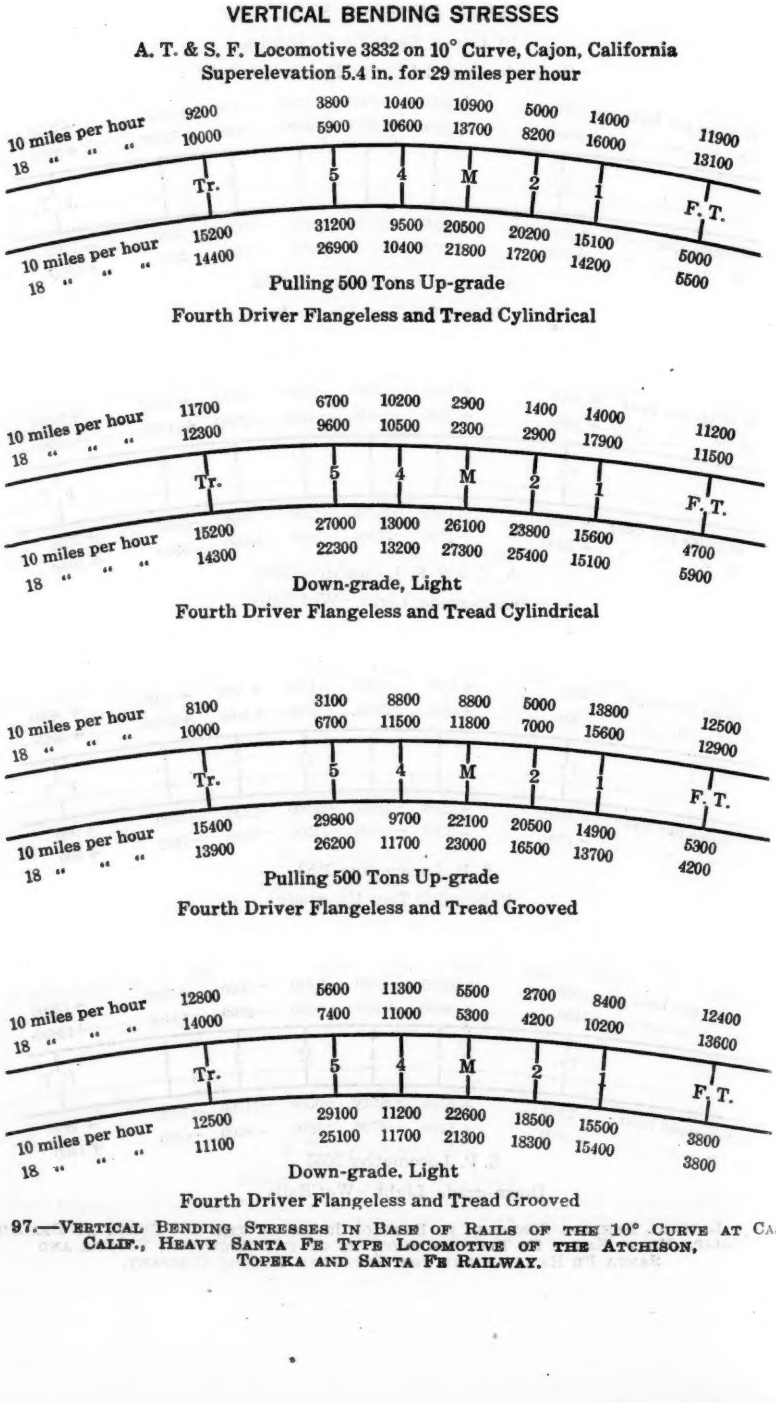


FIG. 97.—VERTICAL BENDING STRESSES IN BASE OF RAILS OF THE 10° CURVE AT CAJON, CALIF., HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

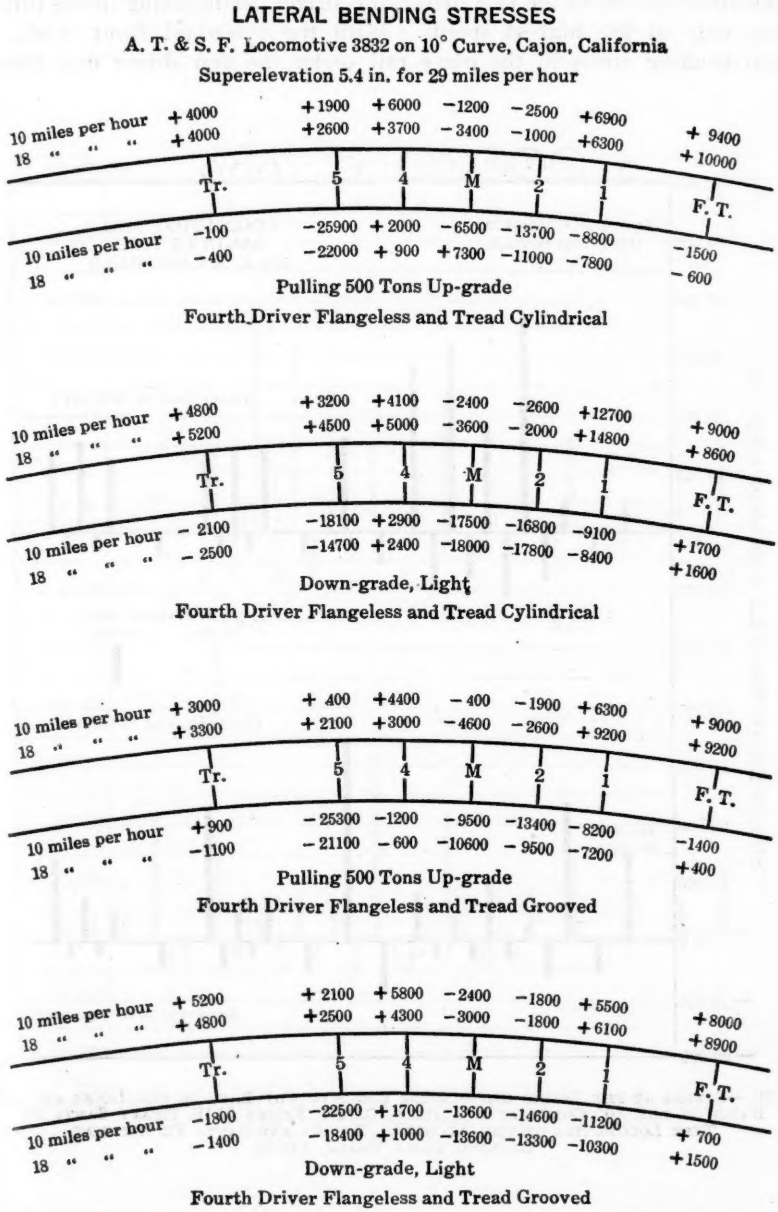


FIG. 98.—LATERAL BENDING STRESSES IN BASE OF RAILS OF THE 10° CURVE AT CAJON, CALIF., HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY.

the four-wheel trucks, there is little or no outward bending stress developed in the outer rail under the first driver, this driver participating in the turning action only at the highest speeds. With the two-wheel front truck, the lateral bending stress in the outer rail under the first driver may become

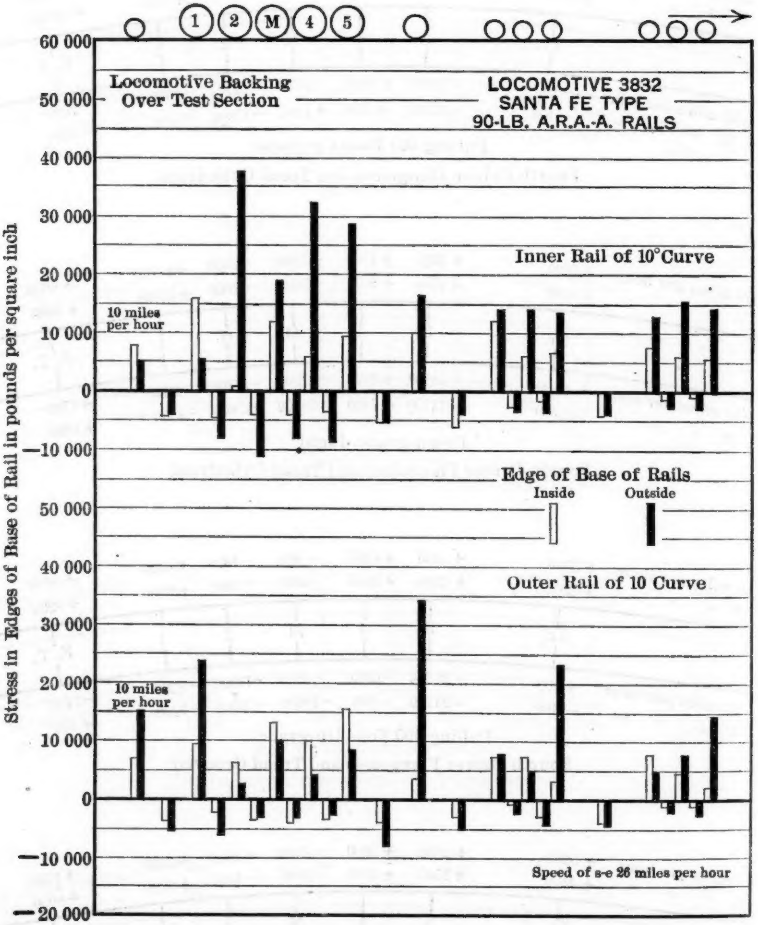


FIG. 99.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 10° CURVE AT BEALVILLE, CALIF., SERIES 5518, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY, BACKING DOWN GRADE, LIGHT.

very great, and the value, 22 600 lb. per sq. in., found under the first driver of the Santa Fe type on the 10° curve, at a speed of 35 miles per hour, may be considered a very excessive stress. It would appear that the use of a four-wheel truck would improve the conditions under the front outer driver of

this locomotive. In the case of the Double Trailer Santa Fe type, the load has evidently been redistributed in such way as to give an increased vertical load on the wheels of the front truck. (It will be recalled that this locomotive was not re-designed for the use of the four-wheel trailer.) The resulting

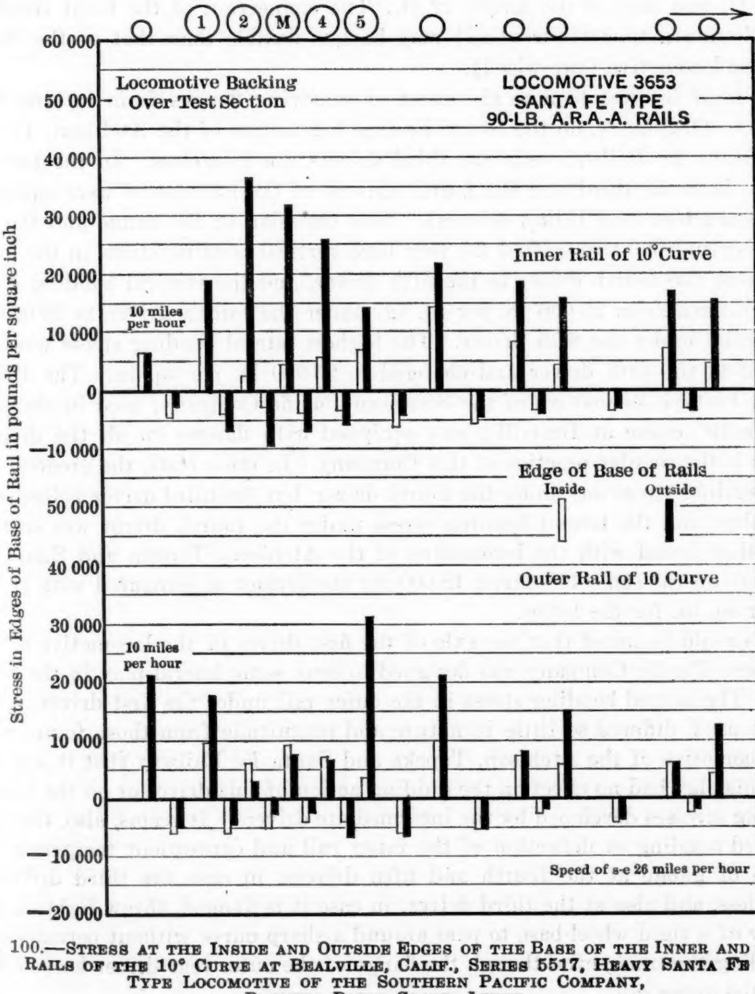


FIG. 100.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 10° CURVE AT BEALVILLE, CALIF., SERIES 5517, HEAVY SANTA FE TYPE LOCOMOTIVE OF THE SOUTHERN PACIFIC COMPANY, BACKING DOWN GRADE, LIGHT.

lateral bending stress at the outer wheel of the truck is very great, 16 000 lb. per sq. in.

The lateral bending stress in the inner rail under the intermediate drivers of these locomotives is so important that its presence and possible magnitude

are matters that should receive careful consideration in designing such locomotives. It is evident that the magnitude of the lateral bending stress in the inner rail may be expected to depend on the wheel-base, although the lateral bending stress under the third driver of the Mountain type on the 10° curve is nearly as great as that under the fourth driver of the Santa Fe type, 19 800 as compared with 23 500 lb. per sq. in. The driver wheel-base of the former is 18 ft. and that of the latter, 22 ft. The connection of the front truck of the Mountain type (four-wheel) may be less flexible than that of the Santa Fe type locomotive (two-wheel).

It is of interest to note the effect of removing flanges from intermediate drivers. Ordinarily, on the Santa Fe type locomotive of the Atchison, Topeka and Santa Fe Railway only the third drivers are flangeless. In the tests at Cajon, both the third and the fourth drivers of the locomotive were equipped with flangeless tires (blind drivers). This omission of the flange and the use of the cylindrical tire shifted the very high vertical bending stress in the inner rail from the fourth driver to the fifth driver, and the vertical bending stress was changed from 29 000 lb. per sq. in. under the fourth driver to 29 000 lb. per sq. in. under the fifth driver. The highest lateral bending stress was also shifted to the fifth driver and changed to 25 900 lb. per sq. in. The Heavy Santa Fe type locomotive of the Southern Pacific Company, used in the tests on the 10° curve at Bealville, was equipped with flanges on all the drivers, which is the regular practice of this Company. In these tests, the greatest lateral bending stress was under the fourth driver, but the third driver helped considerably, and the lateral bending stress under the fourth driver was smaller than that found with the locomotive of the Atchison, Topeka and Santa Fe Railway on the same 10° curve, 18 600 for the former as compared with 25 800 lb. per sq. in. for the latter.

It should be noted that the axle of the first driver of the locomotive of the Southern Pacific Company was designed to have some lateral play in the bearings. The lateral bending stress in the outer rail under the first driver at the speeds used, differed so little in nature and magnitude from those found with the locomotive of the Atchison, Topeka and Santa Fe Railway that it appears that this play had no effect on the guiding action of this driver or on the lateral bending stresses developed by the intermediate drivers. It seems, also, that the outward bending or deflection of the inner rail and consequent temporary increase of gauge at the fourth and fifth drivers, in case the third driver is flangeless, and also at the third driver, in case it is flanged, throw light on the ability of a rigid wheel-base to pass around a sharp curve without permanently spreading the track, even though the flange of the outer rear driver keeps away from the outer rail.

The lateral bending stresses under the trailers of the Mountain and Santa Fe types have high values on the 10° curve, although they are moderate on the 6° curve. It is evident that there is sufficient freedom in turning to give low lateral bending stresses on the 6° curve, but that the restraint on the 10° curve develops high lateral pressures against the outer rail. The double trailer Santa Fe type, however, has such freedom of motion that relatively small lat-

eral bending stresses are developed under these wheels on the 10° curve. It should also be recorded that the lateral springs regulating the lateral swing of the trailer truck in the Mountain type locomotive were loosened for one day's runs; the lateral bending stresses developed in the two rails of the 10° curve with the trailer truck in this condition did not differ particularly from those found when the springs were in their usual condition.

22.—Effect of Pulling and Coasting and of Condition of Rail.—In the discussion of the tests on straight track, it has been shown that the stress in rail under the wheels of the locomotive does not differ greatly whether the locomotive is pulling a load or coasting. On the curved track at Bealville, the average of the vertical bending stresses in base of rail for both outer and inner rails of the 10° curve at all the wheels of the locomotive did not differ noticeably whether the locomotive was pulling a load of 500 tons up grade or whether it was coasting down grade. This load was about one-half the full capacity of the locomotive in operating on the 2.2% grade. The stresses under individual wheels, however, showed some differences.

At Cajon, the stress in the outside edge of the inner rail under the fifth driver (see Figs. 91 to 94) was somewhat greater when the locomotive was pulling load than when coasting for those tests when the tire of the fourth driver was cylindrical (typical of new blind tire), and only slightly greater in the tests, when the fourth driver was grooved. It is seen then that the lateral bending stresses were about the same in the two cases. The vertical bending stresses in the outer rail under the fifth driver were somewhat smaller when the locomotive was pulling. The stresses in the inner rail under the second and third drivers were somewhat smaller when the locomotive was pulling a load than when coasting. The difference in the stresses in the outer rail at the first driver and at the wheel of the front truck (and also the lateral bending stress at other wheels) does not indicate a change that can be considered characteristic. Altogether no very marked differences in stress under the various wheels are noticeable in the two ways of operating the locomotive.

The comparison of the results of the tests at Bealville is complicated by the fact that the down-grade tests were made on wet rails, while in the up-grade tests the rails were dry. It is seen, however, that the vertical bending stress under the rear driver, which is the location giving apparently somewhat higher stresses when the locomotive is pulling load and the one for which higher stresses may possibly be expected for this condition if at all, does not differ in either rail for the up-grade and down-grade tests with either locomotive. It is apparent, however, that there is a considerable difference in the distribution of the stresses under the intermediate drivers due, no doubt, to differences in friction of the wheel on the rail for the two conditions of wet and dry rail and, therefore, to differences in the position of the center of rotation in the change of direction of the locomotive on the curve. At the outside edge of the inner rail, under the fourth driver of the locomotive of the Atchison, Topeka and Santa Fe Railway, the stress drops from 54 700 lb. per sq. in. when the rail is dry (up grade, pulling) to 36 600 lb. per sq. in. when the rail is wet (down grade, light). The stresses under the first, second, and third drivers are some-

what less with the dry rail. The lateral bending stresses in the outer rail under the first driver and the wheel of the front truck are higher with the wet rail. With the locomotive of the Southern Pacific Company, a reduction in stress with the wet rail is found at the main driver, that at the fourth driver remaining the same. It is evident that the condition of the rail has an effect on the development of stress at the different wheels.

23.—Tests with Locomotive Backing over Curved Track.—On curved track, with the locomotive moving forward, the guiding and the change of direction around the curve are effected by the flanges of the outer wheel of the front truck and generally, also, by that of the first driver. When the direction of the locomotive is reversed, it is to be expected that the turning action will be effected by the fifth driver and also by the trailer if its connections are not too flexible. It is also to be expected that the inner second driver will cause large lateral and vertical bending stresses in the rail at the point where the fourth driver develops these large stresses when the locomotive is moving forward. That this reasoning is correct is shown by an examination of Figs. 99 and 100, which give stresses in rail when the Santa Fe type locomotives of the two railroads were backed around the 10° curve at 10 miles per hour, the rails being dry in these tests. The magnitude of the stress at these wheels is not as great as may be expected. It will be noted that, with the locomotive of the Atchison, Topeka and Santa Fe Railway, the turning action is effected by the pressure of the flange of the trailer against the outer rail, while with the locomotive of the Southern Pacific Company the turning action is taken more largely by the fifth driver. Evidently, the trailer of the former locomotive is more restrained in its connections. This restraint was also noticed with a locomotive of the same type in the tests on the 10° curve at Ribera (the locomotive moving forward), but as that restraint did not appear on the 6° curve at Ribera, it would seem that there is sufficient freedom of action in the connection of the trailer not to develop lateral bending stresses under the trailer on the 6° curve.

24.—Lateral Bending of the Rail Section.—When a lateral force is applied to the head of the rail and the base of the rail is held in place either wholly or partly, it may be expected that the rail web will bend and the head of the rail will deflect outwardly or inwardly relatively to the original vertical axis of the rail. To determine whether this lateral bending of the rail section is a measurable quantity, an instrument was made, which was fastened firmly to the base of the rail and had a vertical standard rising at one side of the rail. An Ames dial at the level of the middle of the depth of the head of the rail was attached to this standard; its plunger bore against the side of the head of the rail. The locomotive was run by at a slow speed, 1 to 2 miles per hour, and readings were taken as a wheel passed the instrument and again between wheels. The observation proved to be definite and positive, and succeeding runs confirmed the readings. It should be noted that the observations are independent of any tilting of the rail about its base or its support on the tie; such tilting may also occur.

Measurable values of the lateral bending of the rail section were found. Reference will be made only to the general nature of the results. The deflec-

tion varied from zero to 0.016 in. The values on the 10° curve were somewhat higher than on the 6° curve. The Santa Fe type gave somewhat higher values than the Mountain type. As would be expected from the low speed used, the deflections were greatest in the inner rail, and the direction of deflection in the inner rail was generally away from the track. The direction of the deflection in the outer rail did not always correspond with the character of the observed lateral stress in the base of rail. As the lateral bending of the rail itself is the result of a number of forces, including those acting at the supports of the rail, it is possible that the sign of the bending moment at a wheel point may not be in keeping with the direction of the lateral force acting at that point. An interesting feature occurred when the Santa Fe type was backed over the track. A very high value of the deflection was observed in the inner rail under the fifth driver, a deflection of 0.016 in. away from the track for the 10° curve, and one of 0.014 in. for the 6° curve. The absence of leading wheels to guide the driving wheel-base is evident in these results. Values of the deflection as great as 0.007 in. were found at the wheels of the tender, the middle wheel of a truck on the inner rail giving large deflections.

25.—Preliminary Tests on the Illinois Central Railroad.—Preliminary to the main tests on curved track heretofore described, tests were made on two curves on the Illinois Central Railroad for the purpose of developing the method of testing curved track, of learning the technique necessary for a successful test, and of trying out the instrumental equipment. The results are of sufficient interest to warrant recording.

Fig. 101 gives the stresses in the inner and the outer rail of a 7° curve at Murphysboro, Ill., with a Mikado type of locomotive (No. 1861) of the same general class as that used in the tests on straight track, described in the second progress report, the rail being 90-lb. A. R. A.-A. section, whereas in the earlier tests on straight track the rail was 85-lb. Am. Soc. C. E. section. The super-elevation of the track was 3¾ in., corresponding to a speed of 28 miles per hour. It is seen that the turning action is taken by the flanges of the outer front truck wheel and the first driver, and there is little difference in lateral bending stresses under these wheels at the two speeds used. The fourth driver and the trailer push outwardly on the outer rail at both speeds; the trailer also acts to increase the curvature of the inner rail. The main lateral bending stresses in the inner rail are at the second and third drivers. The vertical bending stress at the third driver, at a speed of 5 miles per hour, is 80% more than that on straight track and, at 25 miles per hour, it is 30% greater than on straight track. In the outer rail, the stresses at the second and third drivers are very small.

Fig. 102 gives the stresses in the inner and outer rail of a 14° curve connecting the Havana Branch at Champaign, Ill. The locomotive is a ten-wheel type (4-6-0). The wheel loads are relatively small. The rail is 85-lb. section. The super-elevation of the track, 3¾ in., corresponds to a speed of 20 miles per hour. It is seen from the stresses that the turning of the locomotive at both speeds is produced by the action of the flanges of the two outer wheels of the front truck. The third driver pushes outwardly on the outer rail at both speeds. The first and second drivers push outwardly on the inner rail, the

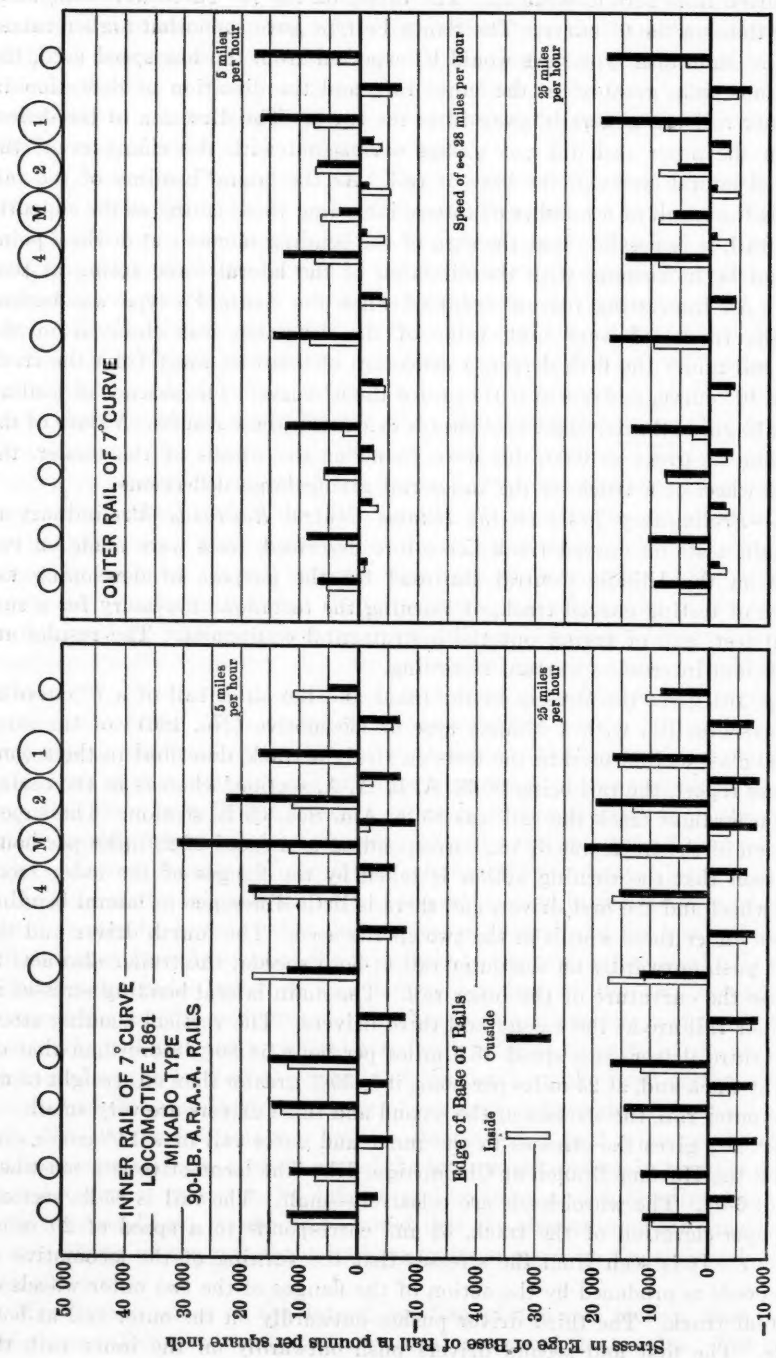


FIG. 101.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 7° CURVE, SERIES 5056–5062, MIKADO TYPE LOCOMOTIVE OF THE ILLINOIS CENTRAL RAILROAD.

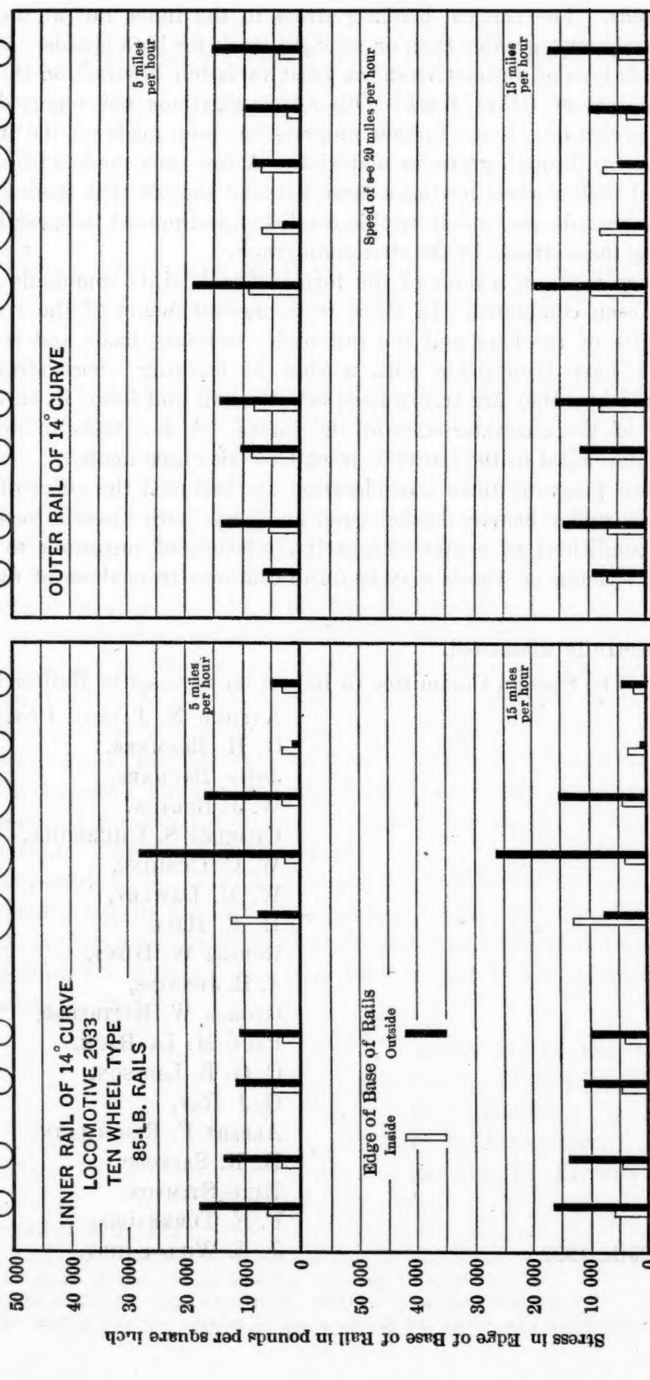


FIG. 102.—STRESS AT THE INSIDE AND OUTSIDE EDGES OF THE BASE OF THE INNER AND OUTER RAILS OF THE 14° CURVE, SERIES 5035–5041, TEN-WHEEL TYPE LOCOMOTIVE OF THE ILLINOIS CENTRAL RAILROAD.

lateral bending stress under the second driver being of considerable magnitude at both speeds. The vertical bending stress in the inner rail at the second driver is nearly 50% greater than on straight track for both speeds. It is seen that even this type of locomotive shows great variation in stress on this curve.

26.—Progress of Other Work.—Other investigations not reported herein have been carried on. Some further progress has been made on the transmission of pressure through granular materials. A few tests made with a loaded car equipped with a wheel having a large flat spot showed that strains of considerable magnitude are caused by this condition and proved the practicability of measuring these strains by the stremmatograph.

Laboratory tests on several of the forms of rail joints commonly used in track have been conducted. In these tests, measurements of the strains in different parts of the bars and the rail under ordinary loads and somewhat higher loads have been made with a view of learning where stresses are developed and how they are transmitted between rail and joint, in an effort to learn more of the characteristics of the joints. A few tests to find what stresses are developed in the joints in track have also been made.

In the test program under consideration are included the effect of canted rails, stresses under heavily loaded cars, and tests with electric locomotives where the conditions of center of gravity, relation of unsprung to sprung weight, and spacing of wheels may be quite different from those of the steam locomotive.

Respectfully submitted,

The Special Committee to Report on Stresses in Railroad Track,

ARTHUR N. TALBOT, *Chairman*,
G. H. BREMNER,
JOHN BRUNNER,
W. J. BURTON,
CHARLES S. CHURCHILL,
W. C. CUSHING,
W. M. DAWLEY,
H. E. HALE,
ROBERT W. HUNT,
J. B. JENKINS,
GEORGE W. KITTREDGE,
PAUL M. LA BACH,
C. G. E. LARSSON,
G. J. RAY,
ALBERT F. REICHMANN,
H. R. SAFFORD,
EARL STIMSON,
F. E. TURNEAURE,
J. E. WILLOUGHBY.

November 29th, 1922.

PROGRESS REPORT OF THE SPECIAL COMMITTEE ON IMPACT IN HIGHWAY BRIDGES*

To the American Society of Civil Engineers:

This Committee was appointed in August, 1922. On account of the short time available for work, only an informal report of progress is possible at this time.

Action by the Committee was begun immediately on its appointment, the first meeting being held in Chicago, Ill., early in September, 1922.

At this meeting, it was decided as a first move to take steps to secure the available information bearing on the work assigned. The Secretary was instructed to write to highway commissions, colleges, experiment stations, and other places, asking for existing data and inquiring about instruments which have been or might be adapted to the problem, and the possibility of co-operation for further work.

A second meeting was held in Chicago on December 13th, 1922, at which the Chairman presented a copy of a preliminary report† of Impact Studies made at Ames, Iowa, during the summer of 1922. With the consent of the co-operating interests, this report, with slight changes, is presented as an Appendix, for the purpose of placing before the Society the data already secured and receiving such discussion as may be accorded it as a guide for future work.

A bibliography on Impact, which promises to be of great service, has been prepared for the use of the Committee by Mr. A. L. Gemeny of the United States Bureau of Public Roads.

It seems likely that the work of the Committee for the coming year will be directed primarily toward co-ordinating a number of otherwise independent projects, studying the problem from theoretic and practical standpoints, and summarizing the work to that time for a report to the Annual Meeting of the Society in 1924.

Almon H. Fuller, *Chairman*,
Clyde T. Morris, *Secretary*,
E. F. Kelley,‡
F. E. Turneaure,
Arthur R. Eitzen.

December 13th, 1922.

* Presented to the Annual Meeting, January 17th, 1923.

† *Bulletin No. 63*, Eng. Experiment Station, Iowa State College.

‡ Mr. Kelley was not present at the meeting, but action was authorized by wire.

APPENDIX

Preliminary Report on Impact Studies on the Skunk River Bridge, on the Lincoln Highway, near Ames, Iowa*

By Almon H. Fuller, M. Am. Soc. C. E.

Introduction

The work was undertaken as a co-operative project of the Iowa State Highway Commission, the Engineering Experiment Station of Iowa State College, and the U. S. Bureau of Public Roads.

The structure selected was the Skunk River Bridge on the Lincoln Highway, 1 mile east of Ames, Iowa, a 150-ft. span, 20-ft. roadway, through-riveted, steel highway bridge, with a 6-in. concrete floor on steel stringers. An elevation of the bridge is shown on Fig. 1.

Although the object was primarily to investigate the effect of impact of trucks and tractors on the particular structure, two related problems naturally presented themselves: First, the distribution of stress throughout various members and portions of members; and, second, the comparison of a number of different instruments and an endeavor to determine which instruments would be the most suitable for future work.

Loads

Two trucks and a caterpillar tractor were used as loads. Their dimensions and concentrations are shown on Fig. 1. Load *A*, consisting of a 3½-ton Liberty truck loaded with gravel, provided a total of nearly 15 tons, with about 12 tons on the rear axle. Load *B*, another 3½-ton Liberty truck, was loaded with kegs of nails and anvils to a total of about 11 tons, with a little more than 8 tons on the rear axle. Load *C* was a 10-ton Holt caterpillar tractor.

In investigating the floor system, Loads *A* and *C* were used separately and Loads *A* and *B* together. For the trusses, Loads *A* and *B* were used together and a train consisting of Load *C* pulling Loads *B* and *A*. The maximum speed of Loads *A* and *B* was about 13 miles per hour and that of Load *C*, about 5 miles per hour, whether used alone or with the train.

Instruments

The instruments used in these tests, were:

(1) Four direct-reading, West extensometers with 20-in. gauge, loaned by the Department of Civil Engineering of Iowa State College.

(2) One Turneaure recording extensometer with a gauge from 48 to 54 in., loaned by F. E. Turneaure, M. Am. Soc. C. E., of the University of Wisconsin.

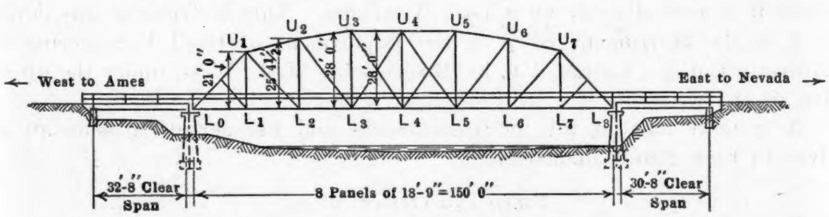
(3) Eight stremmatographs (recording on smoked glass disks) with 20-in. gauge, loaned by A. N. Talbot, Past-President, Am. Soc. C. E., of the University of Illinois.

* *Bulletin No. 63*, Eng. Experiment Station, Iowa State College.

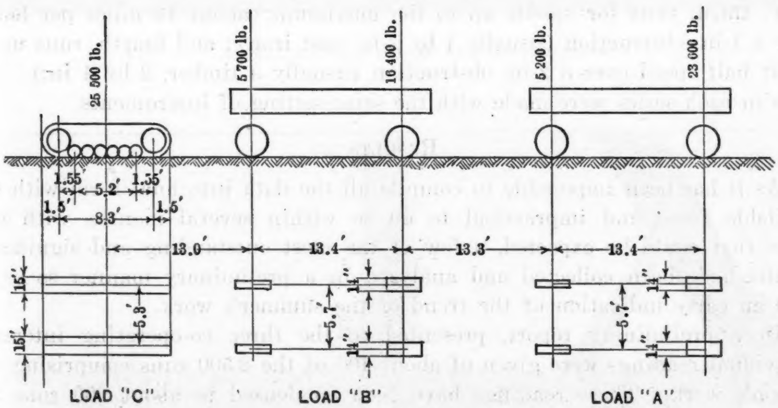
(4) One U. S. Bureau of Public Roads photographic mirror extensometer, with 14-in. gauge, brought out and used by Mr. E. B. Smith, of the Bureau of Public Roads, from September 18th to September 22d, 1922.

(5) One "max" compression instrument of the U. S. Bureau of Public Roads, with 10-in. gauge, brought out and used in the laboratory only by Mr. Smith, from September 18th to September 22d, 1922.

(6) Two "max" compression instruments loaned by C. T. Morris, M. Am. Soc. C. E., of the Ohio State University, with a gauge of about 24 in. (Used for a few days only at the end of the season in field and laboratory.)



ELEVATION OF TEST BRIDGE



IMPACT LOADS

FIG. 1.

(7) One combination instrument arranged by using the smoked glass disks of the stremmatograph on the frame of a West extensometer, with a 20-in. gauge.

(8) One West 20-in. strain gauge, for checking the distribution of stress in stringers, floor-beam, and hip vertical, loaned by the writer.

(9) One Berry 20-in. strain gauge, used as in Item 8, loaned by the Department of Civil Engineering, Iowa State College.

The Turneaure extensometer, which has been used so extensively for impact in railway bridges, has been described.* The stremmatographs developed for measuring the stress in railroad rails by the Special Committee to Report on Stresses in Railroad Track have also been described.†

The West extensometer consists of two yokes about 20 in. apart, held together by a constant distance bar connected (with the necessary freedom of motion) to the center of each yoke. A forked end of each yoke is fastened to the bridge member by two hardened screws. The movement, due to the deformation of the member, is transmitted to the other ends of the yokes where it is read directly on a Last Word dial. This instrument was developed in the Instrument Shop of the Department of Civil Engineering at Lafayette College, Easton, Pa., by Mechanician M. L. West, under the direction of the writer.

A general idea of all the instruments and manner of attachment is given in Figs. 2 to 6, inclusive.

Field and Office Work

The greater part of the field work was done during July and August, 1922. The office work necessary to keep the notes compiled was done, usually, by keeping the force inside for a day or two after several days of work in the field.

Observations were taken for four different conditions of the load: First, at rest for basic static readings; second, runs for various speeds on the clean floor; third, runs for speeds up to the maximum (about 13 miles per hour) over a 1-in. obstruction (usually 1 by 2-in. cast iron); and fourth, runs up to about half speed over a 2-in. obstruction (usually a timber, 2 by 4 in.). All runs in each series were made with the same setting of instruments.

Results

As it has been impossible to compile all the data into final form with the available force and impractical to do so within several months with any force that could be expected, a few of the most outstanding and significant results have been collected and analyzed in a preliminary manner so as to give an early indication of the trend of the summer's work.

In a preliminary report, presented to the three co-operating interests, individual readings were given of about 400 of the 2 500 runs comprising the season's work. These readings have been condensed to about 200 runs for this report and are given in Tables 1 to 8, inclusive. Averages are made for the static loads and for speed runs under various conditions. The results show many inconsistencies which are due to a number of causes, such as condition of the tires, position of the trucks, irregularities of the floor surface, the position of obstructions, in addition to errors of observation, vibration, and inertia of the instruments, etc. Certain characteristics, however, are so persistent that the interpretation of results becomes a matter of determining the degree of precision rather than the general indication.

* *Transactions*, Am. Soc. C. E., Vol. XLI (1899), p. 412, and *Proceedings*, Am. Ry. Eng. Assoc., Vol. XII (1911), Pt. 3, p. 185.

† *Transactions*, Am. Soc. C. E., Vol. LXXXII (1918), p. 1224.

FIG. 2.—LABORATORY COMPARISON AND CALIBRATION.

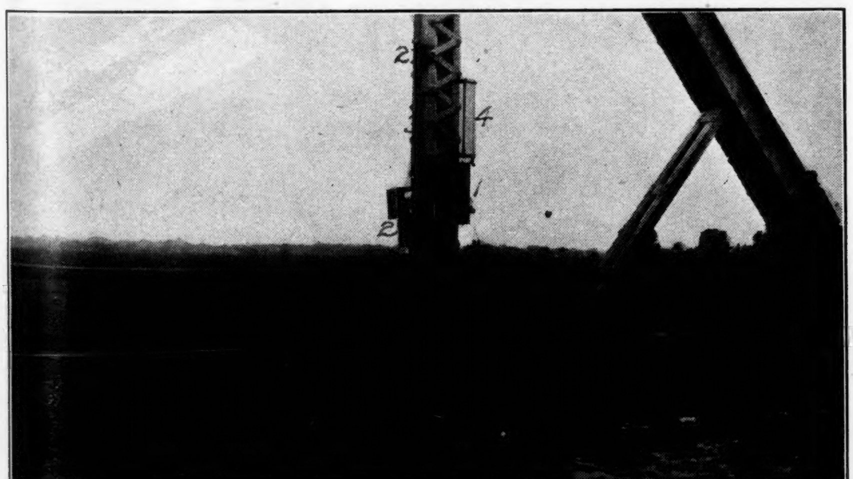


FIG. 3.—EXTENSOMETERS ON HIP VERTICAL U_1 L_1, SOUTH TRUSS, WEST END, SKUNK RIVER BRIDGE.

Papers

FIG.

FIG.

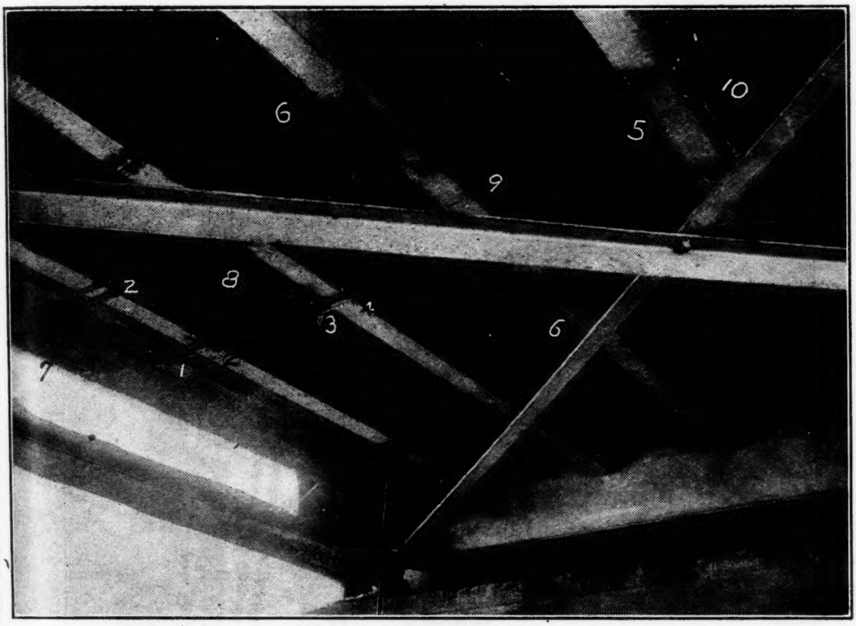


FIG. 4.—STREMMATOGRAPHS AND EXTENSOMETERS ON BOTTOM FLANGES OF STRINGERS, SKUNK RIVER BRIDGE.

FIG. 5.—STREMMATOGRAPHS AND EXTENSOMETERS ON BOTTOM FLANGES OF STRINGERS, SKUNK RIVER BRIDGE.

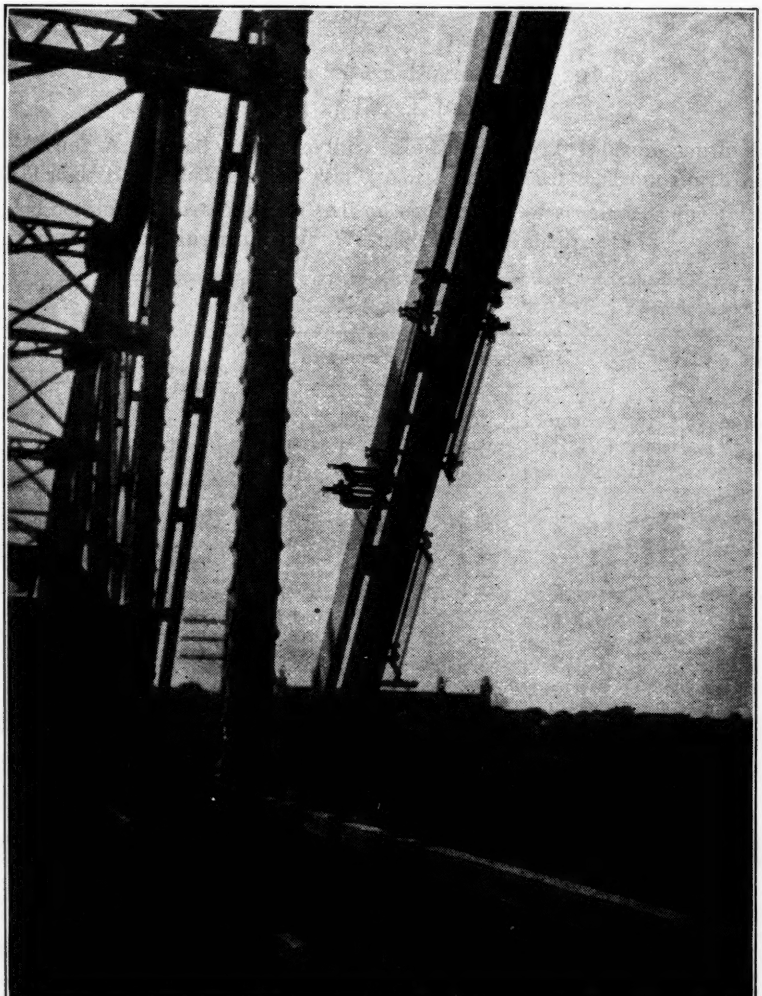


FIG. 6.—EXTENSOMETERS AND STREMMATOGRAPHS ON DIAGONAL $L_6 U_7$, NORTH TRUSS, EAST END, SKUNK RIVER BRIDGE.

Papers.]

Load.—

Run.
1580
1582
1584
1586
Average
1579
1581
1580
1585
1587
Average.
Average
1590
1591
1592
1593
Average.
Average
1598
1599
1600
1601
1602
Average.
Average

TABLE 1.—STRINGER 2.0 FT. NORTH OF SOUTH CURB.

10-IN., 25-LB., I-BEAM.

Load.—Truck A, headed west, moving. South wheel, 1.0 ft. from south curb.
Truck B, headed east, at rest. North wheel, 2.0 ft. from north curb.

Location of instruments: All on center line of stringer span.

Gauge of instruments: West, 20 in.; Turneaure, 48 in.

Run.	Speed, in miles per hour.	Obstruction.	North Flange.				South Flange.	
			Turneaure.		West No. 1.		West No. 2.	
			Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.
1580	0	....	11 300	....	9 300	....	9 600	....
1582	0	....	10 700	....	9 300	....	9 300	....
1584	0	....	10 800	....	9 300	....	9 400	....
1586	0	....	11 000	....	9 300	....	9 600	....
Average static..........			11 000	....	9 300	....	9 500	....
1579	12.8	....	12 300	....	......	....	10 200	....
1581	10.7	....	12 500	....	......	....	9 900	....
1580	10.7	None	11 600	....	9 300	....	......	....
1585	9.1	....	12 800	....	9 800	....	10 200	....
1587	9.8	....	12 500	....	9 700	....	9 900	....
Average...	10.6		12 300	12	9 600	3	10 100	6
Average of two highest..........			12 700	16	9 800	5	10 200	7
1590	11.7	....	15 300	....	......	....	11 600	....
1591	16.0	....	15 300	....	13 100	....	14 500	....
1592	10.7	1 by 2 in.	14 700	....	......	....	......	....
1593	12.8	....	14 700	....	......	....	13 100	....
Average...	12.8	....	15 000	36	13 100	33	13 100	38
Average of two highest..........			15 300	39	......	....	13 800	45
1598	9.1	....	19 500	....	Impossible to read.		Impossible to read.	
1599	9.8	2 by 4 in.	21 500	....				
1600	10.7	South A	23 600	....				
1601	11.7	....	23 100	....				
1602	9.1	....	22 000	....				
Average...	10.0	....	21 900	100				
Average of two highest..........			23 400	112				

TABLE 2.—STRINGER 2.0 FT. NORTH OF SOUTH CURB.
10-IN., 25-LB., I-BEAM.

Load: Truck A, south wheel, 1.0 ft. from south curb.
Truck B, north wheel, 2.0 ft. from north curb.
Both trucks headed west, moving parallel.
Location of instruments: Center line of span.
Gauge of instruments: West, 20 in.; Turneaure, 48 in.

Run.	Speed, in miles per hour.	Obstruction.	NORTH FLANGE.				SOUTH FLANGE.	
			Turneaure.		West No. 1.		West No. 2.	
			Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.
....	....	....	11 200	....	10 800	....	9 900	....
....	....	....	......	....	......	....	......	....
1620	0	....	10 800	....	10 100	....	9 900	....
1621	0	....	11 200	....	10 400	....	9 900	....
1622	0	....	10 600	....	10 400	....	9 600	....
1623	0	....	11 700	....	10 400	....	10 000	....
Average static..........			11 100	....	10 300	....	9 900	....
1634	9.1	....	13 200	....	11 800	....	10 200	....
1630	10.7	....	11 600	....	11 300	....	9 900	....
1632	12.8	None	11 900	....	10 500	....	......	....
1633	10.7	....	12 800	....	11 700	....	......	....
1635	12.8	....	12 300	....	......	....	10 400	....
Average:	11.2	....	12 400	11	11 300	10	10 200	3
Average of two highest..........			13 000	16	11 800	14	10 300	4
1645	14.2	....	19 000	....				
1646	10.7	....	16 000	....				
1647	12.8	....	11 900	....				
1648	12.8	1 by 2 in. North A	18 300	....	Impossible to read.		Impossible to read.	
1649	11.7		18 300	....				
1650	9.8	....	17 100	....				
1651	9.8	....	17 800	....				
1652	14.2	....	17 200	....				
Average	12.0	....	17 000	53	......	....	......	....
Average of two highest..........			18 700	67	......	....	......	....
1653	6.4	....	16 400	....	14 800	....	11 600	....
1654	6.1	....	16 900	....	14 800	....	12 700	....
1655	9.8	2 by 4 in. South A	21 600	....	......	....	......	....
1656	9.8		16 800	....	......	....	11 700	....
Average	8.0	....	17 900	60	14 800	43	12 000	22
Average of two highest..........			19 200	72	14 800	43	12 200	24

TABLE 3.—FLOOR-BEAM AT L_1. 24-IN., 80-LB., I-BEAM.

Load: Trucks A and B, headed west, parallel.
Truck A, south wheel, 2.0 ft. from south curb.
Truck B, north wheel, 2.0 ft. from north curb.

Location of instruments: All 1.5 ft. south of center line.
Gauge of instruments: All 20 in.

Run.	Speed, in miles per hour.	Obstruction.	East Flange.				West Flange.			
			West No. 1.		Stremmatograph No. 4.		West No. 2.		Stremmatograph No. 12.	
			Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.
1864......	0	....	6 500	....	6 500	....	6 700	....	....	....
1865......	0	....	6 500	....	7 400	....	6 200	....	....	....
1866......	0	....	6 700	....	6 700	....	6 400	....	....	....
1867......	0	....	6 500	....	6 800	....	6 400	....	....	....
Average static..............			6 600	....	6 900	....	6 400	....	(6 600)	....
1868......	....	....	7 300	....	8 300	....	....	....	....	....
1869.....	9.8	....	7 400	....	11 600	....	7 300	....	7 500	....
1870......	10.6	....	7 500	....	11 600	....	7 500	....	7 000	....
1871......	12.8	....	7 200	....	9 500	....	7 300	....	....	....
1872......	9.8	None.	7 200	....	10 000	....	7 100	....	12 500	....
1873......	12.8	....	7 100	....	11 600	....	7 000	....	10 000	....
1874......	11.6	....	7 200	....	11 600	....	7 300	....	8 300	....
1875......	9.8	....	7 000	....	11 200	....	7 100	....	....	....
1876......	12.8	....	7 400	....	10 800	....	7 400	....	....	....
1877......	9.8	....	7 200	....	....	....	7 400	....	....	....
Average.	11.1	....	7 200	10	10 700	55	7 300	13	9 000	36
Average of two highest........			7 500	14	11 600	67	7 500	17	11 300	72
1886......	10.6	....	9 400	....	13 700	....	8 800	....	8 300	....
1887......	12.8	....	9 900	....	13 300	....	9 100	....	....	....
1888......	12.8	....	8 700	....	10 800	....	8 700	....	9 100	....
1889......	9.8	None.	7 000	....	10 800	....	8 700	....	8 300	....
1890......	8.5	A 1 in.	....	....	11 600	....	7 300	....	....	....
1891......	10.6	....	9 000	....	13 300	....	8 800	....	10 000	....
1892......	9.8	....	8 700	....	14 500	....	8 000	....	10 400	....
1893......	12.8	....	8 700	....	14 100	....	8 000	....	7 500	....
Average.	10.9	....	8 800	33	12 800	85	8 400	31	8 900	35
Average of two highest........			9 700	46	14 300	106	9 000	40	10 200	55
1899......	7.9	North wheel of Truck A, over 2 by 4 in.	8 600	....	10 000	....	9 100	....	10 000	....
1900......	7.1		9 000	....	8 300	....	8 700	....	8 700	....
1901.....	7.5		8 600	....	....	....	8 800	....	....	....
1902......	7.1		7 100	....	8 100	....	7 700	....	7 900	....
1903......	7.5		7 000	....	7 100	....	7 300	....	9 100	....
Average.	7.4		8 100	23	8 400	22	8 300	30	8 900	35
Average of two highest........			8 800	33	9 200	33	9 000	40	9 600	45
1904......	7.5	Both wheels of Truck A over 2 by 4 in.	8 700	....	8 300	....	9 000	....	10 600	....
1905......	6.4		8 600	....	8 500	....	9 400	....	8 300	....
1906......	5.8		8 600	....	10 000	....	9 100	....	11 500	....
1907......	6.7		8 400	....	8 500	....	9 400	....	....	....
1908......	6.4		9 100	....	10 000	....	10 200	....	9 300	....
Average.	6.5		8 700	32	9 100	32	9 400	47	10 000	52
Average of two highest........			8 900	35	10 000	45	9 800	53	11 100	68

TABLE 4.—Hip Vertical, $U_1 L_1$, South Truss West End. Two 8-In., 11.5-Lb., Channels.

Load: Truck A, headed west; south wheel, 2.0 ft. from south curb.
Truck B, headed west; north wheel, 2.0 ft. from north curb.

Location of instruments: Turneaure, lower point 7.5 ft. above L_1.
West No. 3, lower point 8.75 ft. above L_1.
West No. 4, lower point 8.75 ft. above L_1.

Gauge of instruments: West, 20 in.; Turneaure, 53 in.

Run.	Speed, in miles per hour.	Obstruction.	Northwest Flange. Turneaure. Stress, in pounds per square inch.	Northwest Flange. Turneaure. Impact, percentage.	Northwest Flange. West No. 4. Stress, in pounds per square inch.	Northwest Flange. West No. 4. Impact, percentage.	Southwest Flange. West No. 3. Stress, in pounds per square inch.	Southwest Flange. West No. 3. Impact, percentage.
1864	0	....	4 500	...	4 400	...	2 800	...
1865	0	....	4 400	...	4 400	...	2 500	...
1866	0	....	4 500	...	4 500	...	2 600	...
1867	0	....	4 400	...	4 400	...	2 300	...
Average static			4 500	...	4 400	...	2 600	...
1868	8.5	....	5 200	...	4 400	...	2 900	...
1869	9.8	....	4 900	...	4 900	...	......	...
1870	10.6	None	5 400	...	4 500	...	2 900	...
1871	12.8	....	5 100	...	4 900	...	2 800	...
1872	9.8	....	4 600	...	4 800	...	......	...
1873	12.8	....	4 600		5 200	...	2 800	...
1874	11.6	....	4 800	...	4 500	...	2 900	...
1875	9.8	....	4 600	...	4 800	...	......	...
1876	12.8	....	4 600	...	5 100	...	2 600	...
1877	9.8	....	4 700	...	4 600	...	......	...
Average.	10.8		4 900	10	4 800	9	2 800	8
Average of two highest			5 300	19	5 200	18	2 900	11
1878	12.8	....	8 400	...	Impossible to read.			
1879	9.8	....	7 900	...				
1880	9.8	....	8 900	...				
1881	11.6	1 by 2 in.	9 900	...				
1882	11.6	South A	7 700	...				
1883	9.8	....	6 700	...				
1884	10.6	....	7 600	...				
1885	9.8	....	8 600	...				
Average.	10.7		8 200	85				
Average of two highest			9 400	110				
1894	11.6	2 by 4 in.	11 600	...	Impossible to read.			
1895	11.6	South A	9 200	...				
1896	9.8	....	6 500	...				
1897	9.1	....	7 800	...				
1898	11.6	....	12 400	...				
Average.	10.7	....	9 500	114	......		......	...
Average of two highest			12 000	170	......		......	...

TABLE 5.—DIAGONAL $L_5\ U_6$, NORTH TRUSS EAST END.
TWO $3\frac{1}{2}$ BY 3 BY $\frac{5}{16}$-IN. ANGLES.

Load: Train C, B, A, 2.0 ft. south of north curb headed west.
Location of instruments: West Nos. 2 and 3, lower point 12.5 ft. above L_5
West No. 4, " " 15.5 ft. " "
Turneaure, " " 11.5 ft. " "
Gauge of instruments: West, 20 in.; Turneaure, 48 in.

Run.	Speed, in miles per hour.	Obstruction.	NORTH ANGLE.				SOUTH ANGLE.			
			West No. 3.		West No. 4.		West No. 2.		Turneaure.	
			Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.
2198	0	....	4 400	....	4 600	....	4 800	....	5 200	....
2198	0	....	4 900	....	4 800	....	5 400	....	5 200	....
2200	0	....	4 900	....	4 600	....	5 400	....	5 200	....
2201	0	....	4 500	....	4 500	....	5 400	....	5 300	....
Average tension static.........			4 700		4 600		5 300	....	5 200	....
2210	0	....	−2 300	....	−2 300	....	−2 200	....	....	....
2211	0	....	−2 300	....	−2 300	....	−2 200	....	....	....
2212	0	....	−2 300	....	−2 300	....	−1 800	....	....	....
2213	0	....	−2 300	....	−2 300	....	−1 900	....	−1 000	....
2214	0	....	−2 200	....	−2 300	....	−2 000	....	−1 000	....
2215	0	....	−2 300	....	−2 300	....	−2 000	....	−1 000	....
Average compression static....			−2 300	....	−2 300	....	−2 000	....	−1 000	....
2202	5.0	....	5 200	....	6 500	....	5 800	....	6 500	....
2203	5.0	....	5 500	....	7 000	....	5 700	....	6 700	....
2204	5.0	....	5 500	....	6 100	....	5 800	....	6 600	....
2205	5.0	....	5 400	....	6 400	....	5 800	....	6 800	....
2206	5.0	None.	4 800	....	6 200	....	6 100	....	7 000	....
2207	5.0	....	−4 100	....	−4 200	....	−2 900	....	....	....
"	"	....	4 800	....	6 100	....	5 800	....	6 200	....
2208	5.0	....	−3 500	....	−4 200	....	−2 500	....	....	....
"	"	....	4 900	....	6 100	....	5 500	....	6 400	....
2209	5.0	....	−2 800	....	−3 900	....	−2 900	....	....	....
"	"	....	5 500	....	6 100	....	5 800	....	....	....
Average tension...............			5 200	11	6 300	37	5 800	10	6 600	27
2217	5.0	All wheels over 2 by 4 in. at L_5	6 000	....	6 500	....	−2 600	....	....	....
					−4 100	....	6 100	....	6 600	....
2218	5.0		6 000	....	7 000	....	−2 900	....	....	....
					−3 800	....	6 200	....	7 800	....
2219	5.0		6 200	....	7 100	....	−2 600	....	....	....
					−4 200	....	5 800	....	6 800	....
2220	5.0	....	5 500	....	6 500	....	....	....	....	....
					−3 600	....	....	....	7 400	....
2221	5.0	....	6 100	....	6 200	....	....	....	....	....
					−4 100	....	7 300	....	7 200	....
Average tension...............			6 000	28	6 700	46	6 800	19	7 200	38

TABLE 5.—(*Continued.*)

Run.	Speed, in miles per hour.	Obstruction.	North Angle.				South Angle.			
			West No. 3.		West No. 4.		West No. 2.		Turneaure.	
			Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.
2222	5.0	....	—4 600	....	5 800 —5 100	....	....	....	—1 700 6 200	....
2223	5.0	All wheels over 2 by 4 in at L_6	—4 400	....	5 500 —5 100	....	....	....	—2 600 6 800	....
2224	5.0		—4 900	....	5 800 —5 700	....	....	....	—2 000 6 700	....
2225	3.0	....	—6 200	....	—5 800	....	—2 900 5 800	....	—1 600 6 500	....
2226	3.0	....	—5 100	....	5 500 —4 800	....	—2 900 5 800	....	—1 600 6 500	....
2227	4.0	....	—5 100	....	5 100 —4 400	....	—2 600 5 800	....	—1 100 6 300	....
Average tension					5 500	20	5 800	10	6 600	27

NOTE.—All figures not preceded by a minus sign are plus (tension).

Comparison of Instruments

The West extensometers and the stremmatographs were calibrated in standard testing machines on a steel bar in tension for relation between actual unit stresses and the reading of the instruments, and on the vibrating apparatus of the Bureau of Public Roads for inertia and vibration. The West instruments showed a remarkably satisfactory behavior in every respect and apparently assure results which have a precision equal to that with which the needle of the dial can be easily read.

The stremmatograph also gives evidence of being reliable, when working normally, but to a much less degree of precision. The time required for adjusting the disks in the field and reading them in the office would apparently produce fewer data with less precision (particularly for the lower stresses) than the same time devoted to either the West or the Turneaure extensometers.

No suitable testing machines, or other apparatus, were available for calibrating the Turneaure extensometer in direct tension or for inertia or vibration. It was calibrated, in connection with all the other instruments, on the tension flange of an I-beam in flexure. As all the readings were dependent on the initial tension in the connecting rod, which was not constant, the calibrations have not yet been extended sufficiently to insure confidence in the precision of the results. It seems apparent, however, that this instrument has added materially to the confidence which may be placed on the season's work as a whole. It has furnished significant data for high impacts resulting from the blows of the truck wheels in passing over obstructions. This is particularly helpful when it was impossible to read the dial on the West instruments, as illustrated in Table 1 for Runs 1598 to 1602 on stringers.

TABLE 6.—POST $U_6\ L_6$, NORTH TRUSS EAST END.
TWO 8-IN., 11.5-LB. CHANNELS.

Load: Train C, B, A, headed west, 2.0 ft. from north curb.
Location of instruments: West, lower point, 9.0 ft. above L_6
Turneaure, " " 8.0 ft. " "
Gauge of instruments: West, 20 in.; Turneaure, 48 in.

Run.	Speed, in miles per hour.	Obstruction.	NORTHEAST FLANGE. West No. 1. Stress, in pounds per square inch.	NORTHEAST FLANGE. West No. 1. Impact, percentage.	SOUTHEAST FLANGE. West No. 2. Stress, in pounds per square inch.	SOUTHEAST FLANGE. West No. 2. Impact, percentage.	SOUTHEAST FLANGE. Turneaure. Stress, in pounds per square inch.	SOUTHEAST FLANGE. Turneaure. Impact, percentage.	SOUTHWEST FLANGE. West No. 3. Stress, in pounds per square inch.	SOUTHWEST FLANGE. West No. 3. Impact, percentage.	NORTHWEST FLANGE. West No. 4. Stress, in pounds per square inch.	NORTHWEST FLANGE. West No. 4. Impact, percentage.
2166	0	......	−2 600	......	−2 300	....	−2 800	....	−2 300	....	−1 700	....
2168	0	......	−2 800	......	−2 800	....	−2 900	....	−1 900	....	−1 900	....
2169	0	......	−2 600	......	−2 800	....	−2 700	....	−1 900	....	−1 900	....
2175	0	......	−2 300	......	−2 800	....	−2 700	....	−1 900	....	−2 000	....
2176	0	......	−1 900	......	−2 300	....	−2 700	....	−1 600	....	−1 700	....
2177	0	......	−2 600	......	−2 600	....	−2 800	....	−1 900	....	−1 700	....
2178	0	......	−2 000	......	−2 500	....	−2 700	....	−1 700	....	−1 600	....
Average compression static			−2 300	......	−2 600	....	−2 800	....	−1 900	....	−1 800	....
2179	0	......	1 500	......	2 200	....	2 400	....	1 000	....	2 200	....
2180	0	......	......	......	2 200	....	2 700	....	1 200	....	2 300	....
2181	0	......	400	......	2 200	....	2 600	....	1 200	....	2 200	....
2182	0	......	600	......	2 200	....	2 800	....	1 200	....	2 300	....
Average tension static.....			800	......	2 200	....	2 600	....	1 200	....	2 200	....
2170	5.0	......	......	......	7 500	....	3 400	....	......	....	3 600	....
			−3 300	......	−3 800	....	−3 100	....	−2 500	....	−2 300	....
2171	5.0	......	2 900	......	7 300	....	3 400	....	2 900	....	4 300	....
			−3 300	......	−3 600	....	......	....	−2 300	....	......	....
2172	5.0	......	2 300	......	8 700	....	3 400	....	3 000	....	4 100	....
			−3 200	None	−3 600	....	−2 900	....	−2 000	....	......	....
2173	5.0	None	2 800	......	1 300	....	3 000	....	2 600	....	5 100	....
			−3 500	......	−3 300	....	−2 900	....	−2 200	....	−2 500	....
2174	5.0	......	3 000	......	9 400	....	3 100	....	2 900	....	6 500	....
			−3 200	......	−4 100	....	......	....	−2 200	....	−2 500	....
2173	5.0	......	1 000	......	5 800	....	3 300	....	1 500	....	4 400	....
			−2 800	......	−2 900	....	......	....	−2 000	....	......	....
2184	5.0	......	900	......	7 300	....	3 600	....	2 500	....	4 100	....
			−2 600	......	−2 600	....	......	....	−2 000	....	......	....
2185	5.0	......	1 000	......	5 100	....	4 300	....	2 300	....	4 100	....
			−2 800	......	−2 900	....	......	....	−1 900	....	......	....
Average compression......			−3 100	35	−3 400	30	−3 000	7	−2 100	10	−2 400	33
2186	5.0		1 000	......	7 300	....	3 700	....	2 200	....	4 500	....
			−2 800	......	−2 900	....	−2 900	....	−2 200	....	−2 600	....
2187	5.0		900	......	7 300	....	3 300	....	2 900	....	4 400	....
			−3 000	......	−2 900	....	......	....	−2 600	....	−2 600	....
2188	5.0	All	900	......	7 300	....	3 100	....	3 000	....	4 200	....
		wheels	−3 000	......	−2 900	....	−3 100	....	−2 000	....	−2 800	....
2189	5.0	over	900	......	8 000	....	3 300	....	3 900	....	4 600	....
		2 by 4	−2 900	......	−2 900	....	−3 000	....	−2 000	....	−2 800	....
2190	5.0	in.	700	......	5 800	....	3 800	....	3 600	....	4 200	....
			−2 600	......	−2 900	....	−2 900	....	−2 000	....	−2 000	....
Average compression......			−4 300	87	−2 900	11	−3 000	7	−2 200	16	−2 600	45

TABLE 6.—(*Continued.*)

Run.	Speed, in miles per hour.	Obstruction.	NORTHEAST FLANGE. West No. 1. Stress, in pounds per square inch.	NORTHEAST FLANGE. West No. 1. Impact, percentage.	SOUTHEAST FLANGE. West No. 2. Stress, in pounds per square inch.	SOUTHEAST FLANGE. West No. 2. Impact, percentage.	SOUTHEAST FLANGE. Turneaure. Stress, in pounds per square inch.	SOUTHEAST FLANGE. Turneaure. Impact, percentage.	SOUTHWEST FLANGE. West No. 3. Stress, in pounds per square inch.	SOUTHWEST FLANGE. West No. 3. Impact, percentage.	NORTHWEST FLANGE. West No. 4. Stress, in pounds per square inch.	NORTHWEST FLANGE. West No. 4. Impact, percentage.
2191	5.0		......	......	8 000	....	6 800	....	5 800	....	7 200	....
			−2 800	......	......	....	......	....	−2 200	....	−2 200	....
2192	5.0	All wheels over 2 by 4 in. at L_6	......	......	7 300	....	3 800	....	4 500	....	6 500	....
			−2 800	......	−2 900	....	−2 900	....	−2 000	....	−2 200	....
2193	5.0		......	......	5 800	....	4 500	....	4 200	....	6 500	....
			−2 600	......	......	....	−2 900	....	......	....	−2 200	....
2194	5.0		......	......	7 300	....	4 800	....	4 800	....	5 800	....
			......	......	......	....	......	....	......	....	−2 200	....
2195	5.0		......	......	8 000	....	6 800	....	6 500	....	7 300	....
			......	......	−2 800	....	......	....	−2 000	....	−2 200	...
2196	5.0	....	......	......	6 500	....	3 900	....	4 100	....	6 100	....
			......	......	......	....	......	....	......	....	−2 000	....
2197	5.0	....	......	......	7 700	....	5 200	....	4 600	....	7 400	....
				......	−2 800	....	......	....	−2 200	....	−2 200	....
Average compression......			−2 700	18	−2 800	8	−2 900	4	−2 100	10	−2 200	23

NOTE.—All figures not preceded by a minus sign are tension (plus).

The fact that the dial could not be read indicates a much higher impact than in the preceding runs where it could be read. The Turneaure extensometer not only gives the same indication, but suggests a value. It will be noticed that the impact percentages are usually in closer accord than the unit stresses and, as impact is the factor most needed, the matter of calibration, under static stress, loses some of its apparent importance.

The continuous vibration produced by the caterpillar tractor was reflected in the erratic behavior of the instruments of which the West extensometer seemed to be the most affected. Calibration has not yet been extended sufficiently to secure a satisfactory interpretation, except that this vibration seems more or less distinct from the inertia due to single blows and of greater effect at times, and that many of the suggested impacts are doubtless too high.

Stresses and Impact

The average impact percentages from Tables 1 to 8, inclusive, have been tabulated in Tables 9, 10, and 11, after taking some liberty in combining the results of two or more instruments on the same member. These results are recorded first by instruments, and from these values a figure has been suggested as a probable impact percentage for the member and the loading.

The basis for the interpretation of these impacts will be illustrated by a few references. In Table 1, for the second stringer, Truck B was at rest and Truck A moving; whereas, in Table 2, both loads were moving. The apparent inconsistencies between the two sets of runs, where the impact is more for the 1-in. obstruction and less for the 2-in. obstruction, when both

TABLE 7.—West Approach Span, Stringer 2.0 Ft. North of South Curb.

15-In., 55-Lb., I-Beam.

Load: Truck A, headed west 1.0 ft. from south curb.

Location of instruments: All on center line of span.

Gauge of instruments: West, 20 in.; Turneaure, 48 in.

Run.	Speed, in miles per hour.	Obstruction.	North Flange.				South Flange.	
			Turneaure.		West No. 4.		West No. .	
			Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.	Stress, in pounds per square inch.	Impact, percentage.
2011	0	....	5 200	....	5 300	....	5 100	....
2012	0	....	5 200	....	5 500	....	5 100	....
2013	0	....	5 100	....	5 500	....	5 100	....
Average static			5 200	....	5 400	....	5 100	....
2014	11.9	....	6 200	....	6 700	....	7 300	....
2015	11.9	....	6 200	....	6 700	....	6 400	....
2016	10.8	....	6 200	....	6 500	....	6 100	....
2017	11.9	....	6 300	....	6 700	....	6 400	....
2018	11.9	None	6 000	....	6 700	....	5 900	....
2019	12.5	....	6 000	....	6 700	....	5 900	....
2020	11.4	....	6 500	....	7 000	....	6 500	....
2021	10.8	....	6 500	....	6 700	....	6 400	....
2022	11.9	....	6 300	....	7 000	....	5 900	....
2023	10.8	....	6 200	....	6 700	....	5 800	....
2024	10.4	....	6 500	....	6 700	....	6 200	....
2025	11.9	....	6 600	....	6 500	....	5 900	....
Average...	11.4	....	6 300	21	6 700	24	6 200	22
Average of two highest		....	6 600	27	7 000	30	6 900	35
2026	13.3	....	7 000	....	6 800	....	8 400	....
2027	10 8	....	8 000	....	7 200	....	8 700	....
2028	10.4	....	7 100	....	8 000	....	6 400	....
2029	10.4	1 by 2 in.	6 800	....	7 200	....	7 400	....
2030	11.4	South A.	7 100	....	7 700	....	7 700	....
2031	11.4	....	7 800	....	8 000	....	8 700	....
2032	10.8	....	7 000	....	7 800	....	8 000	....
2033	10.4	....	7 200	....	7 800	....	7 800	....
2034	10.4	....	7 100	....	7 500	....	8 400	....
2035	10.4	....	7 000	....	8 000	....	8 100	....
2036	11.9	....	7 400	....	8 000	....	6 500	....
2037	11.4	....	7 100	....	7 800	....	8 600	....
2038	11.9	....	7 500	....	8 300	....	8 000	....
2039	10.4	....	7 100	....	6 700	....	7 000	....
Average...	11.0	....	7 200	39	7 600	41	7 300	43
Average of two highest		....	7 900	52	8 200	53	8 700	70
2052	5.6	....	8 000	....	8 300	....	8 400	....
2053	5.6	....	7 500	....	8 500	....	7 700	....
2054	6.3	2 by 4 in.	7 300	....	8 200	....	7 500	....
2055	5.7	South A.	7 500	....	7 500	....	7 500	....
2056	6.5	....	7 100	....	7 500	....	7 000	....
2057	6.3	....	7 500	....	8 000	....	7 500	....
2058	6.3	....	7 800	....	8 700	....	8 400	....
2059	7.2	....	7 200	....	8 300	....	7 500	....
2060	6.8	....	7 500	....	8 700	....	7 700	....
Average...	6.2	....	7 500	44	8 200	52	7 700	51
Average of two highest		....	7 900	52	8 700	61	8 400	65

TABLE 8.—WEST APPROACH SPAN, STRINGER UNDER SOUTH CURB.
15-IN., 55-LB., I-BEAM.

Load: Truck A, 1.0 ft. north of south curb, headed west.
Location of instruments: Center line of span.
Gauge of instruments: All 20 in.

Run.	Speed, in miles per hour.	Obstruction.	NORTH FLANGE. West No. 2. Stress, in pounds per square inch.	NORTH FLANGE. West No. 2. Impact, percentage.	NORTH FLANGE. Stremmatograph No. 12. Stress, in pounds per square inch.	NORTH FLANGE. Stremmatograph No. 12. Impact, percentage.
2011......	0	....	3 300	......	2 800	......
2012......	0	....	3 300	......	2 800	......
2013......	0	....	3 300	......	2 800	......
Average static........			3 300	......	2 800	......
2014......	11.9	....	4 600	......	3 500	......
2015......	11.9	....	4 200	......	3 100	......
2016......	10.8	....	4 100	......	3 200	......
2017......	11.9	....	3 900	......	3 200	......
2018......	11.9	....	4 100	......	3 500	......
2019......	12.5	....	4 100	......	......	......
2020......	13.0	None.	4 500	......	3 200	......
2021......	10.8	....	4 400	......	3 300	......
2022......	11.9	....	4 500	......	3 400	......
2023......	10.8	....	4 200	......	......	......
2024......	10.4	....	4 600	......	......	......
2025......	11.9	....	4 500	......	......	......
Average.	11.6	....	4 300	30	3 300	18
Average of two highest........			4 600	39	3 500	25
2026......	13.2	....	5 500	......	3 200	......
2027......	10.8	South wheels	5 900	......	4 200	......
2028......	10.4	over	6 400	......	......	......
2029......	10.4	1 by 4 in. at	6 400	......	......	......
2030......	11.3	mid-span.	5 800	......	......	......
2031......	11.3		7 400	......	......	......
2032......	10 8	....	6 700	......	......	......
2033......	10.4	....	6 800	......	......	......
Average.	11.0	....	6 400	94	3 700	32
Average of two highest........			7 100	115	......	......
2052......	5.6	South wheels	4 500	......	......	......
2053......	5.6	over	5 400	......	......	......
2054......	6.3	2 by 4 in. at	5 500	......	4 500	......
2055......	5.7	mid-span.	5 500	......	......	......
2056......	6.5	....	5 700	......	......	......
2057......	6.3	....	6 100	......	......	......
2058......	6.3	....	5 600	......	......	......
2059......	7.2	....	5 500	......	......	......
2060......	6.8	....	6 200	......	......	......
Average.	6.2	....	5 600	70	4 500	61
Average of two highest........			5 900	79	......	......

trucks are moving, may be due to the possibility that, in the first instance, the maximum effects of both trucks were simultaneous, and, in the second, they were timed so as to counteract each other. The brackets in Table 9 indicate impacts beyond the practicability of reading the dial of the West instruments, as indicated in Tables 1 and 2, and thus serve to substantiate the high impacts of the Turneaure extensometer. For the floor-beams, with both trucks, Table 3, there is a marked contrast between the readings of the West extensometer and the stremmatograph for the clean floor and the 1-in. obstruction and a close check for the 2-in. obstruction. The results of the West instrument are given greater weight for the first two conditions, because of general dependence for the lower impacts and the fact that the impact indicated by the stremmatograph for the clean floor is far greater than any other checked result for the floor without obstruction.

TABLE 9.—PERCENTAGE OF IMPACT IN STRINGERS.

Runs.	Speed, in miles per hour.	Obstruction.	Trucks A and B.				Truck A.				Tractor C.			
			West.	Turneaure.	Stremmatograph.	Probable.	West.	Turneaure.	Stremmatograph.	Probable.	West.	Turneaure.	Stremmatograph.	Probable.
South Outside Stringer, 0.5 Ft. North of South Curb.														
1707-1713.....	13.4	....	....	....	....	....	9	....	33	10	....	....	....	....
1717-1724.....	13.4	1 in.	....	....	....	....	106	....	160	100	....	....	....	....
1725-1728.....	6.9	2 in.	....	....	....	....	152	....	130	140	....	....	....	....
1787-1794.....	....	....	....	....	....	....	....	....	....	....	72	....	170	(?)
1797-1822.....	....	....	....	....	....	....	....	....	....	....	....	....	112	(?)
Second Stringer, 2.0 Ft. North of South Curb.														
40-166........	8.9	....	....	....	....	....	17	....	13	15	....	....	....	....
96-172........	8.7	1 in.	....	....	....	....	38	....	28	30	....	....	....	....
1579-1587.....	10.6	....	5	12	....	10	....	....	....	....	....	....	....	....
1590-1593.....	12.8	1 in.	35	26	....	35	....	....	....	....	....	....	....	....
1598-1602	10.1	2 in.	( )	100	....	75	....	....	....	....	....	....	....	....
1624-1635.....	11.2	....	7	11	....	10	....	....	....	....	....	....	....	....
1645-1652.....	12.0	1 in.	( )	53	....	50	....	....	....	....	....	....	....	....
1653-1656.....	8.0	2 in.	( )	60	....	50	....	....	....	....	....	....	....	....
1707-1713.....	13.5	....	....	....	....	....	4	4	....	4	....	....	....	....
1717-1724.....	13.3	1 in.	....	....	....	....	....	46	....	40	....	....	....	....
1725-1728.....	6.9	2 in.	....	....	....	....	(68)	38	....	40	....	....	....	....
1787-1801.....	5.0	....	....	....	....	....	....	....	....	....	200	18	....	(?)

For the hip vertical, $U_1 L_1$, Table 4, the West and the Turneaure extensometers check nicely for the clean floor, but only the Turneaure yielded readable results when obstructions were placed. Both instruments, however, indicate very high impacts for this member, a result which was also apparent in a few observations in 1921.

In the west approach span, there is a remarkable coincidence between the West and the Turneaure instruments on the second stringer (Table 7) and a large discrepancy between the West instrument and the stremmatograph on the first or outside stringer (Table 8) especially for the 1-in. obstruction,

The general tendency to give the greater weight to the West extensometer is counterbalanced by the fact that these particular readings indicate unusually high impact, and, therefore, do not inspire the same degree of confidence as the lower indications. An average figure, therefore, is used in Table 11.

TABLE 10.—PERCENTAGE OF IMPACT IN DIAGONALS AND VERTICAL POSTS.

Member.	Runs.	Speed, in miles per hour.	Obstruction.	Trucks A and B. West.	Trucks A and B. Turneaure.	Trucks A and B. Stremmatograph.	Trucks A and B. Probable.	Train C, B, A. West.	Train C, B, A. Turneaure.	Train C, B, A. Stremmatograph.	Train C, B, A. Probable.
U_2 L_3	853-855	6.4	....	23	19	....	....	....	....	....	....
	860-862	6.8	2 in.	73	82	....	....	....	....	....	....
	874-875	6.9	2 in.	90	150	....	....	....	....	....	....
U_3 L_4	691-695	7.1	....	22	....	....	....	....	....	....	....
	698-700	8.9	1 in.	31	....	....	....	....	....	....	....
	712-715	4.7	2 in.	65	....	....	....	....	....	....	....
	708-711	6.8	2 in.	68	....	....	....	....	....	....	....
U_6 L_7	2154-2157	5.0	....	....	....	....	....	7	3	....	5
	2158-2165	5.0	2 in.	....	....	....	....	15	12	....	15
L_5 U_6	2202-2209	5.0	....	....	....	....	....	20	27	....	20
	2217-2221	"	2 in. at L_5	....	....	....	....	30	38	....	30
	2222-2227	"	2 in. at L_6	....	....	....	....	15	27	....	....
VERTICAL POSTS.											
U_2 L_2	917	7.5	......	20	....	....	....	....	....	....	....
	918- 923	6.3	2 in.	50	....	....	....	....	....	....	....
	932- 935	6.1	2 in.	70	....	....	....	....	....	....	....
U_6 L_6	2170-2185	5.0	......	....	....	....	....	30	7	....	25
	2186-2190	5.0	2 in. at L_5	....	....	....	....	40	7	....	30
	2191-2197	5.0	2 in. at L_6	....	....	....	....	15	4	....	....
U_5 L_5	2234-2238	5.0	......	....	....	....	....	42	20	....	30
	2239-2243	5.0	2 in. at L_4	....	....	....	....	110	30	....	60
	2244-2248	5.0	2 in. at L_5	....	....	....	....	65	10	....	....

The "probable percentages" of impact, previously referred to, have been taken from the data just discussed and given in Table 12, after again taking liberty in combining various results for the same class of members and for the two different obstructions. In admitting that these values have been selected by judgment, based on observation, rather than by true averages, it is pointed out that some of the original data have been given and that any one interested may draw his own conclusions.

The condensed results will be discussed separately for a clean floor and for obstructions. For the clean floor, there is no indication of impact of more than 15% for the floor system and hip verticals of the main span. The suggestion of higher impact for the truss members and for the stringers of the approach span may be due to the cumulative effect as the load travels a greater distance.

TABLE 11.—Percentage of Impact, Miscellaneous.

Runs.	Speed, in miles per hour.	Obstruction.	Trucks A and B.				Truck A.				Tractor C.			
			West.	Turneaure.	Stremmatograph.	Probable.	West.	Turneaure.	Stremmatograph.	Probable.	West.	Turneaure.	Stremmatograph.	Probable.
Hip Verticals, $U_1 L_1$.														
1831-1841	4.8	......	....	....	....	....	....	....	....	....	170	80	105	100
1868-1877	10.8	......	9	10	...	10	....	....	....	....	....	....	....	....
1878-1885	10.7	1 in.	( )	85	....	100	....	....	....	....	....	....	....	....
1894-1898	10.7	2 in.	( )	114	....	125	....	....	....	....	....	....	....	....
Floor-Beam at L_1.														
1853-1863	4.7	......	....	....	....	....	....	....	....	....	70	....	....	70
1868-1877	11.1	......	12	....	45	15	....	....	....	....	....	....	....	....
1886-1893	10.9	1 in.	32	....	60	35	....	....	....	....	....	....	....	....
1899-1903	7.4	2 in.	27	....	29	30	....	....	....	....	....	....	....	....
1904-1908	6.5	2 in.	40	....	42	40	....	....	....	....	....	....	....	....
West Approach Span, South Outside Stringer.														
2014-2025	11.6	......	....	....	....	....	30	....	18	25	....	....	....	....
2026-2033	11.0	1 in.	....	....	....	....	94	....	32	60	....	....	....	....
2052-2060	6.2	2 in.	....	....	....	....	70	....	61	65	....	....	....	....
West Approach Span, Stringer 2 Ft. North of South Curb.														
2014-2025	11.4	......	....	....	....	....	23	21	....	20	....	....	....	....
2026-2039	11.0	1 in.	....	....	....	....	42	39	....	40	....	....	....	....
2052-2060	6.2	2 in.	....	....	....	....	52	44	....	50	....	....	....	....

TABLE 12.—Summary of Impact Percentages.

Condensed from Tables 9, 10, and 11.

Load.	A		A-B		C-B-A		C
Condition of floor members.	Clean.	Obstruction.	Clean.	Obstruction.	Clean.	Obstruction.	Clean.
Approach Span:							
Stringers	25	50	..	..	..	..	..
Main Span:							
Stringers	15	50	15	50	..	..	100
Floor-beam	..	..	15	35	..	..	70
Hip vertical.......	..	..	10	100	..	..	100
Intermediate posts.	..	..	..	..	30	60	..
Diagonals.........	..	..	20	75	20	30	..

It may be well to call attention to the fact that full speed (about 13 miles per hour) was used for the 1-in. obstructions, but that it was thought prudent to keep the speed to about one-half that amount when the 2-in. obstruction was used. The impacts were about the same for the two cases. There are

many indications of impact of more than 50% and several of more than 100 per cent.

The foregoing discussion has been based on percentages of impact which are averages of all runs for each condition. As a matter of interest, an average of the two highest stresses has been added in each instance. When the two averages differ to a great extent, the higher indications are probably from an unusual combination of conditions which sometimes occur. These should be recognized and provided for, but possibly not by the usual unit stresses.

Too great reliance should not be placed on the high individual results recorded on such members as stringers and hip verticals, which receive a very direct effect from sudden blows, such as were used in these experiments. Difficulties due to inertia effects in the instruments and in securing reliable readings under such conditions, make the problem very troublesome, and the values here recorded should be considered in the light of these facts. The use of the mirror extensometer of the U. S. Bureau of Public Roads in future experiments promises to give much information on this particular phase of the problem.

It seems evident that the percentage of impact on a highway bridge is likely to be small when the floor is clean and the tire is in good condition, but that a considerable impact is likely to occur with defective solid tires, chains, blocks of wood, small pieces of rock, and other obstructions which may be encountered.

More study and mature judgment are necessary in determining the impact to be provided within the usual unit stresses and also for the higher unit stresses which may be allowed for the high impacts which are likely to occur under certain conditions, but at long intervals.

Distribution of Stress

Stringers.—Figs. 7, 8, and 9 show the distribution of observed static stress due to Loads *A* and *C* among the stringers of the main span and to Load *A* on the stringers of the approach span. As a means of comparison of the total stresses for the various positions of the loads among themselves and with computed stresses, the sums of observed stresses are given for each position and compared with the total stresses which would be indicated by the usual methods of computation. To the computed unit stresses, under the usual assumption that the steel stringers carry all the load as simple beams, have been added the computed unit stresses under an imperfect T-beam action. These computations were ingeniously made, by R. A. Caughey, M. Am. Soc. C. E., after the neutral axis had been located by strain-gauge readings, under the assumption that the compression in the concrete floor plus the compression in the steel stringers would equal the tension in the stringers. Sufficient data have not been secured to determine to what extent the differences between observed and computed stresses may be due to partial continuity of the stringers.

An analysis of the results shows, for the stringers of the main span, that when the live load is placed at the center of the roadway, the greatest

stress in one stringer equals about one-eighth the total computed stress and about one-sixth the total observed stress, and when the load is placed near one side, that the stringer nearest the outside one is stressed about one-fifth the total stresses as indicated by computations and about one-fourth those shown by the measurements.

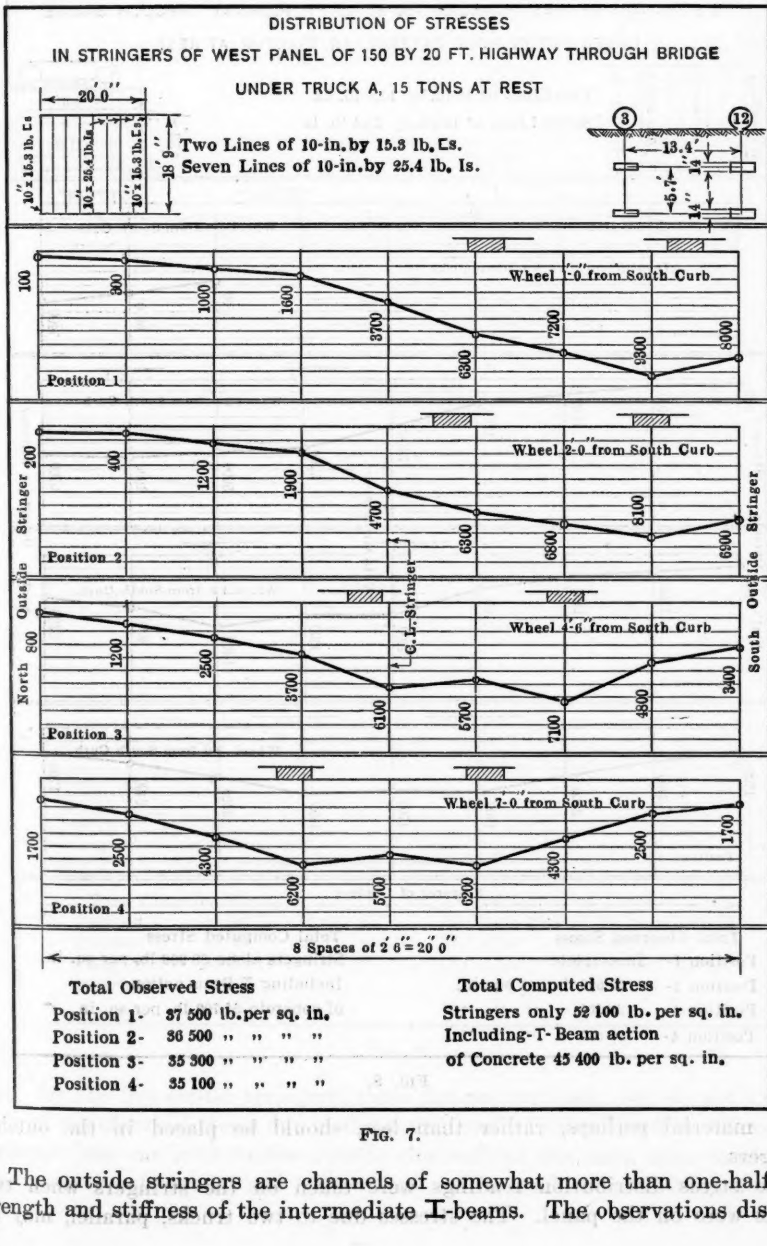


FIG. 7.

The outside stringers are channels of somewhat more than one-half the strength and stiffness of the intermediate I-beams. The observations disclose

the inadequacy of these outside stringers to give the necessary support to the second stringer and suggest that, in order to keep the stresses and the deflection of the two outside stringers within the range of the intermediate ones,

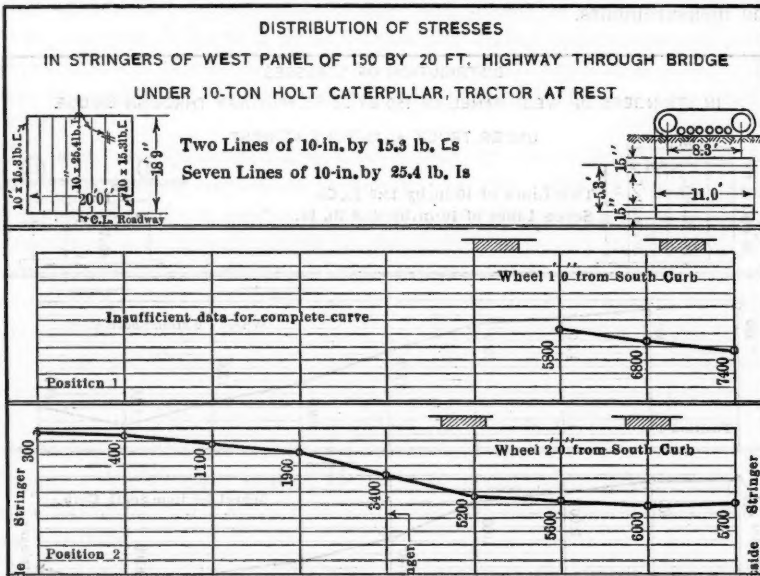


FIG. 8.

more material perhaps, rather than less, should be placed in the outside stringers.

No stress distribution readings were taken on the stringers when two trucks were on the panel. The stresses due to two trucks, parallel, may be

anticipated by adding the stresses in each stringer due to one load separately on each side of the roadway. Additions have been made for the two different loads on the main span and for the one load on the approach span. In each

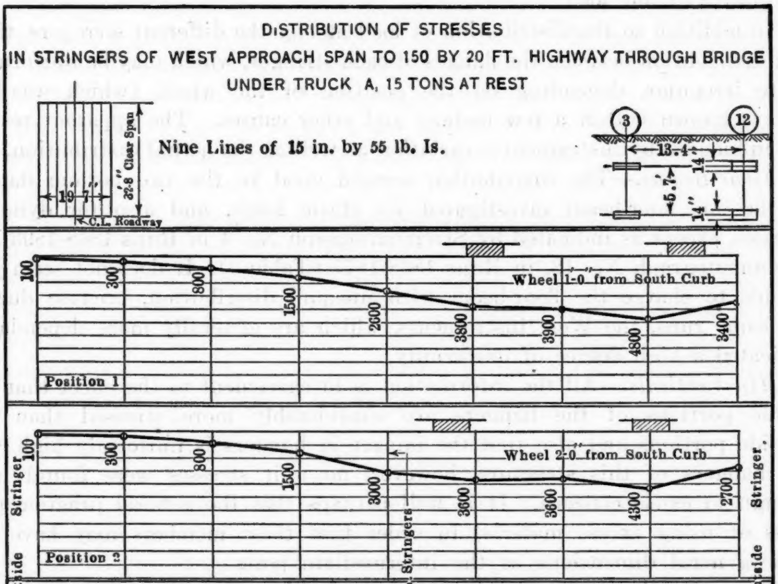


FIG. 9.

case, for the five center stringers, these figures approach, but do not exceed, 25% of the observed stress due to the entire load. Under Truck A, the second stringer (the one next to the outside channel) of the main span would evidently carry between 25 and 30% of one entire truck, but, as suggested pre-

viously, this is a situation which could be relieved in design. On the approach span, where the outside stringer is of the same size as the others, the maximum load on the second stringer, with two loads on the span, appears to be about one-fourth of one load.

In addition to the distribution of load among the different stringers, there is a distribution between the flanges of each stringer, which may be uniform or quite irregular, depending on the position of the wheel (which was not always known within a few inches) and other causes. The apparent results are influenced by instrumental variation as well as the actual distribution.

Floor-Beams.—The distribution seemed good in the two bottom flanges of the one floor-beam investigated for static loads, and also for dynamic stresses, except as indicated by Stremmatograph No. 4 in Runs 1868-1893 and Stremmatograph No. 12, in Runs 1868-1877 (Table 3). It does not seem justifiable to charge the floor-beam with unequal distribution, because during the same runs, the West instruments, which are generally more dependable, indicated a high degree of uniformity.

Hip Verticals.—All the information is in agreement to the effect that the inside portions of the hangers are considerably more stressed than the outside portions and also that the impact in hangers is uniformly high. In the hangers of this structure, however, no unit stresses were found high enough to cause concern. It is well perhaps that the general practice prevails of using excess material in order that these members may have the same general dimensions as the intermediate posts.

Truss Members.—The tendency in the hangers for greater stress in the inside of the members is also apparent in all the intermediate posts and the diagonals. It is less, however, in the diagonals than in the hangers and still less in the intermediate posts.

Strain-Gauge Checks.—No systematic checks were attempted by use of the strain gauge, although a number of static readings were taken on the second stringer in the west panel, the floor-beam at L_1 and the hip vertical, $U_1\ L_1$, on the west end of the north truss. No thorough comparison has yet been made of these results with those from the extensometers, and the strain-gauge notes are not incorporated in this report. They are available, however, for any further study which may be made. Sufficient consideration has been given them to make it apparent that they check, in a general way, the magnitude and the distribution of the static stresses obtained by the other instruments. These results have been of particular service already in locating the neutral axis of the stringers.

New Photographic Mirror Extensometer of the U. S. Bureau of Public Roads

The work was planned with the expectation that the new photographic mirror extensometer designed and built by the U. S. Bureau of Public Roads would be available. It did not arrive, however, until the active field work was closed. Mr. E. B. Smith, Senior Testing Engineer for the Bureau, who had a large part in the development of the instrument, kindly consented to bring it for comparison with the instruments used during the season and

reached Ames on September 18th, 1922. It was used in comparison with all the other instruments on the bridge and for laboratory calibrations on September 18th, 19th, and 21st, 1922.

One of the most interesting parts of the laboratory work was a comparison, on the flanges of a 12-in. by 31.5-lb. I-beam in flexure, of the new instrument with the Turneaure instrument, two West instruments, a stremmatograph, two Morris "max" compression instruments, and a "max" instrument brought out by Mr. Smith. These instruments are shown in Fig. 2. Fig. 3 shows the photographic instrument, the Turneaure, and two West instruments on the west hip vertical of the south truss of the Skunk River Bridge. The readings show a close comparison of the photographic and West instruments on the northwest flange and of the Turneaure and a West instrument on the northeast flange, but a decided difference in impact between the two flanges when obstructions were used. It seems probable that the obstructions were placed so that the blows of the truck wheels were applied slightly to the east of the center of the floor-beam (the far side) and that the effect of these blows was greater on that side of the hanger.

Possibilities for Future Work

It is no less evident now than when the work was started (and perhaps no more so) that the problem would not be completed in 1922, in fact, that it would be just begun. Assuming that the problem should be investigated in a scientific manner and laws or even empirical formulas deduced, the work would naturally include:

A.—Investigations for:

1. Other span lengths;
2. Other types of structures;
3. Other floor surfaces;
4. Other loads with various tires.

B.—Certain studies to be made on this and other structures, such as:

1. The effect of speed;
2. The effect of tractor treads;
3. The effect of the condition of solid tires;
4. The effect of sudden starting and stopping;
5. Stress distribution to be checked against computed secondary stresses;
6. The relation between the intensity of a blow such as may be struck by a truck wheel and the resulting stresses in a structure;
7. The relation between impact and the roughness of floor pavement.

Instruments for Future Work

Every instrument used has contributed to the value of the work. It has been mentioned, however, that there was considerable variation in the consistency of results and in the time consumed in taking and in compiling them.

The work has disclosed the desirability of two distinct types: Direct-reading and self-recording. A recording instrument has naturally the greatest value, as it gives a graphic picture of stress variations during the passage of a load. Direct readings are almost indispensable in giving instant indications of the intensity of stresses, thus making it possible to "feel the way", to avoid conditions of over-stress, and to serve as a check on the graphic record. The possibilities of the personal factor in making occasional faulty set-ups, of instruments getting out of adjustment, of neglect to make the proper identification of any particular reading, and other causes, are so great that occasional, if not constant, checks should be made by different instruments.

As a recording instrument, the photographic mirror extensometer of the U. S. Bureau of Public Roads appears to be the most satisfactory, and it seems desirable that a sufficient number of these instruments should be constructed so that they may be available for the coming season. For direct readings, the West instrument has given the most consistent results for static loads and low impacts. Recent trials indicate that by choking the dials, high impacts as well may be accurately observed.

No one instrument combines the factors of approximate immediate results, positive identification, quick computations, and permanent record like the Turneaure extensometer. It seems that the gauge length is too long and the force necessary to put the instrument in action is too great to give results as high in precision as those just mentioned. Yet, it is an instrument which should be welcomed on any impact investigation.

The Morris "max" instrument, although slower in action and less precise in results, would be of special value when large impacts were under observation and the other instruments were not yielding consistent results.

The stremmatograph, although perhaps the most cumbersome in use and the least precise for small stresses, might be even the best available for certain high stresses under severe impact conditions. The combination of the stremmatograph and the West instrument, as mentioned previously, might well be considered in this connection.

Strain-gauge readings for distribution of stress under static loads will always add a finish to any extended series of stress measurements.

Number of Instruments.—It would be well, in work of this nature, to have at least eight instruments on each of the thirty odd members of each truss and at least two on each of the eighty-one stringers and floor-beams, with a few defectometers and other special instruments. Then, with a few applications of each of a few different loads, assuming that all of them work perfectly all the time, a very interesting and rather complete story would be told of the elastic behavior of the structure. This is manifestly impossible. Four instruments, one for each of the four flanges of the ordinary member, seem to be the minimum number which would be efficient; and with four, the efficiency would be low. It would seem desirable that no working party be sent out with less than eight instruments, of which four or more should be of a recording type.

ORGANIZATION

The Highway Commission was represented by the writer, who was in general charge, and by Messrs. Herbert Schmidt and R. J. De La Hunt (each working about half time) as Observers. The Commission also furnished truck drivers, all the loads, staging, and nearly all the supplies.

The Experiment Station furnished the services of Professor Caughey who was in direct charge of field and office work and of Messrs. L. W. Bartow and W. H. E. Dunham, Observers.

The U. S. Bureau of Public Roads furnished the services of Mr. J. W. Hewes and Frank Kerekes, Jun. Am. Soc. C. E., throughout the season and Mr. E. B. Smith, Senior Testing Engineer, for a few days in September, 1922, during which the new photographic mirror extensometer was used in checking the instruments used during the working season.

PROGRESS REPORT OF THE SPECIAL COMMITTEE ON ELECTRIFICATION OF STEAM RAILWAYS*

THE AMERICAN SOCIETY OF CIVIL ENGINEERS,
GENTLEMEN:

Your Special Committee on Electrification of Steam Railways submits a progress report as follows:

This Committee was appointed in February, 1922, but as all the original appointees did not qualify, the Committee, as now constituted, was not finally formed until later. Although it has had no meeting, there has been an exchange of views by correspondence, which has resulted in a general understanding as to the scope of the work to be undertaken. Considerable information regarding the subject to be investigated has been collected. The Committee hopes that in its subsequent reports it may have its investigations in hand to such an extent as will justify the statement of some underlying principles governing the electrification of steam railroads.

Several societies and associations have special committees considering various phases of the electrification of steam railroads. Your Committee understands that under its instructions it is privileged to confer with such committees and, in due time, will doubtless desire to establish some contacts of this nature. However, so far, this has not been attempted, pending a decision as to the extent to which this Committee should attempt to investigate this quite large subject, especially as it appears that other similar committees are generally confining their investigations largely to the more technical phases of this problem.

Your Committee inclines to the opinion that the broad question of the electrification of steam railroads is not primarily, or even largely, a question of the choice of a particular system or type of electrification; but, on the contrary, and especially at this time, is more largely dependent on financial and economic conditions; that if these conditions, in any case, justify the cost of electrification, little or no difficulty would be had in the selection of the system or type of electrification which would reasonably meet the requirements. Your Committee proposes, therefore, to study the subject first from the viewpoint of the economics of the problem.

Doubtless, there are cases which would result in benefits alike to the public and to the railroads. That this applies, in general terms, to any large number of localities or railroads is probably not true. Public interest in electrification is mostly confined to large urban districts, in the expectation that a material reduction of smoke and noise would result. Although it is true that there

* Presented to the Annual Meeting, January 17th, 1923.

would be some advantages in these regards, it is possible that the results would be comparatively small in view of the many sources of smoke and noise other than railroads. There are doubtless situations, principally in large terminals and in thickly populated urban districts, where electrification may be very desirable, perhaps even necessary, and where the question of the economies resulting from the change may have to be made a secondary consideration. Such situations are in a class by themselves and must have consideration independently of the larger and broader problem of the electrification of railroads over considerable distances, in order that they may be made more efficient and economical transportation agencies. The electrification of railroads by operating divisions becomes, therefore, a somewhat different and more important problem than the greater number of electrifications thus far made in the United States.

The economies which are usually effected by electrification do not often enter into the whole range of transportation costs, but are confined largely to the cost of power and its applications, and those items of transportation cost which are affected by a change in form of motive power and changes in operating conditions made possible thereby. One of the conditions affecting the quantity and cost of power is the volume of traffic. If this conclusion is correct, the electrification of steam railroads, where undertaken primarily as a means of increasing efficiency and economy, can be expected first on those roads, or parts of such roads, where the volume of traffic is large, or, where the volume of traffic in connection with ruling gradients calls for large expenditures of power. It also appears probable that a further condition necessary to economy would be that the change from steam to electric power should be made effective over continuous stretches of railroad of considerable length.

To change a railroad from steam to electric operation requires not only a large expenditure of new capital, but also the abandonment and retirement of many existing facilities. Under conditions such as have existed during the last few years, and still exist, the additional capital for electrification would be difficult to arrange for and, in the case of many railroads, would be impossible. The wiping out of existing investments by retirements, although largely a matter of accounting, presents a practical difficulty of no small magnitude. As a practical matter, therefore, the electrification of steam railroads may be expected to be effected only on a showing of substantial benefits which would result in lowering transportation costs and leave the railroads a return somewhat more than sufficient to justify the increased financial burdens which the change would involve.

If made to include one or more operating divisions, electrification would most likely also include the urban terminals where the public benefits arising from it would be enjoyed. On the contrary, the electrification of large terminals only, brought about solely by local conditions, would not extend the benefits of electrification for the public beyond that immediate locality, and might prove to be an added burden rather than an economy for the railroad.

The Committee is desirous that it be understood as making the preceding statements as generalities; they are not to be considered at this time even as tentative conclusions. They indicate some of the phases of the subject to which the Committee will give careful consideration.

Respectfully submitted,

C. F. LOWETH, *Chairman*,
BION J. ARNOLD,
GEORGE GIBBS,
GEORGE W. KITTREDGE,
E. J. PEARSON,
SAMUEL REA,
ROBERT RIDGWAY.

DECEMBER 13TH, 1922.

TECHNICAL PAPERS
PRESENTED AT THE ANNUAL MEETING
JANUARY 17, 1923

ENGINEERING EDUCATION

THE NEW PROJECT FOR THE SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION

By Charles F. Scott,* Esq.

At the Annual Convention of the Society for the Promotion of Engineering Education, in June, 1922, the Council appointed a Development Committee to formulate an answer to the question, "What can the Society do in a comprehensive way to develop, broaden and enrich engineering education?"

The following is quoted from the report of the Committee:

"The engineer of to-morrow will be called upon to take even a more important part than the engineer of to-day in great enterprises, both private and public. He will be called upon for general service in organization and leadership as well as for technical service in the solution of new problems (industrial, economic, governmental and social) which the engineering applications of science have produced. This means imagination, vision, the power to conceive, and the ability to carry out great projects.

"The problem of engineering education is to determine and to meet the progressive demands of a rapidly changing civilization. What constitutes these demands is a question being considered by educators, by engineering societies, by organizations of industries and public utilities and by others. Unfortunately, there has been almost no co-ordination of effort, and there is lack of agreement on even fundamental objectives. The first necessity then would seem to be an investigation to determine just what the facts are."

* * * * * * *

"The question involves two fundamental inquiries:

"A.—What the engineer graduate should be.

"B.—What the training of the engineering student should be and the influence surrounding him.

"Your Committee would therefore recommend:

"I. That there be created within the Society, a Board of Investigation and Co-ordination, consisting of five (5) members, under whose general direction there should be organized and conducted (*a*) an active campaign for the promotion of engineering education in light of the needs of the future as those needs may be developed; (*b*) there shall be co-ordinated as far as possible the activities of the various agencies interested in promoting engineering education; and (*c*) there shall be conducted research in engineering education."

* * * * * * *

"III. That there be authorized a director, with an adequate staff.

"IV. That progress reports to the Society be published periodically."

* * * * * * *

"VI. That the objects (among others) for which the Board is created shall be considered to be:

"1. To ascertain the facts in engineering education, such as concerns (*a*) teachers, their origin, training, experience, and effectiveness; (*b*) teaching facilities; (*c*) curriculums; (*d*) students and graduates, their origin, training, experience and effectiveness.

"2. To ascertain present and future requirements in the fields served by engineer graduates.

* Pres., Soc. for the Promotion of Eng. Education; Prof. of Elec. Eng., Sheffield Scientific School, Yale Univ., New Haven, Conn.

"3. To present the facts and requirements for their bearing on the training of the engineer to the end that he may (*a*) develop himself and his profession; (*b*) realize and fulfill his obligation to society.

"4. To maintain close contact with engineering schools enabling them to participate in the investigations, and reporting to them from time to time, to the end that the developments may be continuous from the initial contact between the colleges and the agencies of the Board.

"5. To secure the necessary funds for these purposes."

The report has been approved and the members of the Committee have been appointed as members of the Board. They are as follows: Dean M. E. Cooley, M. Am. Soc. C. E., of the University of Michigan; John H. Dunlap, M. Am. Soc. C. E., formerly Professor of Hydraulics and Sanitary Engineering, State University of Iowa, now Secretary of the American Society of Civil Engineers; Dugald C. Jackson, M. Am. Soc. C. E., Professor of Electrical Engineering, Massachusetts Institute of Technology; F. W. McNair, President, Michigan School of Mines; and the speaker. F. L. Bishop, Secretary of the Society for the Promotion of Engineering Education, is Secretary of the Board.

A letter, on behalf of the Board, was sent to presidents and deans of engineering colleges asking suggestions and co-operation by the schools. The responses were encouraging and constructive.

The full functioning of the Board must await the securing of funds and the selection and appointment of a Director and staff.

The increasing general interest in engineering education is significant. The National Industrial Conference Board and the Society for the Promotion of Engineering Education have recently formed an Advisory Conference Committee on Engineering Education. The members representing industry are: S. P. Bush, President, Buckeye Steel Castings Company, Columbus, Ohio; H. E. Coffin, Vice-President, Hudson Motor Car Company, Detroit, Mich.; Col. T. C. Dickson, U. S. A., Commanding Officer, U. S. Arsenal, Watertown, Mass.; Howard Elliott, Affiliate, Am. Soc. C. E., Chairman, Northern Pacific Railroad, New York City; E. M. Herr, President, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.; William H. Nichols, Chairman, Allied Chemical and Dye Corporation, New York City; A. H. Rogers, President, Mining and Metallurgical Society of America, New York City; and, Henry D. Sharpe, Treasurer, Brown and Sharpe Manufacturing Company, Providence, R. I.

The members representing the educational society are as follows: R. H. Fernald, Professor of Mechanical Engineering, University of Pennsylvania, Philadelphia, Pa.; H. J. Hughes, M. Am. Soc. C. E., Dean, Harvard Engineering School, Cambridge, Mass.; D. C. Jackson, Professor of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.; F. W. McNair, President, Michigan School of Mines, Houghton, Mich.; J. W. Roe, Professor of Administrative Engineering, New York University, New York City; H. Schneider, Assoc. M. Am. Soc. C. E., Dean, College of Engineering and Commerce, University of Cincinnati, Cincinnati, Ohio; and the speaker.

It was a surprise to the Committee to find practical unanimity in the view that engineering education for the industries should be along broad lines

with thorough training in the fundamentals of science and engineering, leaving much of the training in the special processes of an industry to experience to be gained from the industry after graduation. It was the general view that the narrowly or specially trained man was not fitted for development into the positions of larger responsibility and leadership which industry needs; that the industries at present are not appreciative to what a degree their development and expansion is dependent on their securing men of engineering training and giving them opportunities for development. It is anticipated that the Industrial Conference Board not only will awaken industry to a new attitude toward science and engineering, but that it will be most helpful to the engineering schools by giving a clearer specification as to the type and number of men which industry needs and will assist by co-operating with the schools in making their training most effective.

The Highway Education Board is significant as a forward movement. Leaders in highway transport are making education a prime factor in the program for the development of highway transport. One is tempted to ask whether the railroads would be in the position they now are, if they had cultivated education in past years and had grafted into their organizations generous numbers of men of scientific and engineering training. Certainly, conditions would not be as they are at present in which there is little demand or opportunity for college graduates in railway service, and research in the railway field is practically at a standstill.

Engineering and scientific societies have been taking a new interest in engineering education. The American Institute of Mining and Metallurgical Engineers and the American Chemical Society have already issued reports on education. Dean Cooley who recently visited engineering societies and engineering schools in a third of the States in his travels as President of The Federated American Engineering Societies and Secretary Dunlap who made many visits in his recent journey to and from the meeting of this Society in San Francisco, Calif., both report a general and animated interest in engineering education.

The Presidential Address to the American Society of Mechanical Engineers by Dean Kimball in December, 1922, was entitled "National Leadership". In his address, Dean Kimball showed that our civilization differs from those that have gone before in our power to produce the necessities of life, to feed, clothe, and house the multitude. He traced the changes wrought by modern methods on industrial life and the resulting complexity of human relations. Modern civilization is largely what the engineer has made it and the civilization of the future will be largely what he wishes it to be. Modern civilization, however, is not what it should be—production has increased, but adequate social benefit has not resulted. The engineer for the first time is face to face with the great problems of human relations in industry and the distribution of wealth. A new form of industrial leadership is needed, but the source of this leadership does not seem to be clear. In history, National leadership was first a military rule, succeeded by legal government. Industry has had these types, and two other types are available for industrial leadership, namely, the busi-

ness and financial type and the scientific type. Dean Kimball showed why and how the engineering type of mind is adapted to make a great contribution to the solution of industrial and National problems.

Most engineers will agree with Dean Kimball that the extending field of the engineer must logically include, not only the technical and the strictly professional, but also participation in leadership in industry and in public affairs.

Industrial, social, economic, political, National, and international problems are largely those which are incident to the new world brought about by science and engineering. The opportunities, the responsibilities, and the obligations of the engineer to-day differ from those of fifty years ago in proportion as the field and influence of engineering itself has grown; and the opportunity and responsibility of the engineer in the next generation can be predicted only as we project into the future the curves of engineering and related activities and attempt to formulate the various problems which the next generation will bring forth.

Engineers themselves have realized a field of service beyond that of their old-time technical societies and have formed The Federated American Engineering Societies which is making available the service of the engineer in a new way.

Anticipating that the engineer of the future must be bigger and broader than the engineer of to-day, it becomes necessary to provide the new engineer. This is the function of the engineering school, but not of the school alone. Engineers and engineering societies, industry, and others as well, should consider what the engineer of the future should be, what type of boys should be chosen, and what education and training they should receive in school and after graduation, in order that the engineer of the future may be adequate for his new responsibilities.

The Engineering Profession has been unique in having a National organization for the promotion of engineering education. The Society was formed at the Columbian Exposition in 1893. Through conventions, with papers and discussions, with reports of standing committees of which there are a score, and by its publications, it has promoted the ideals and the practice in the training of engineers. Through its initiative, the report of Dr. Mann of the Carnegie Foundation for the Advancement of Teaching was produced, which has awakened thought and discussion. The new project of the Society has been undertaken in recognition of the new demands on engineering schools. It is not a plan by which some super-committee shall evolve a formula for engineering education. It rather contemplates active interest and participation by the schools in formulating and solving the problems which are primarily their problems.

The schools are alert to new methods. Co-operation with industry, administrative engineering courses, discussions regarding the lengthening of the course from four to five or six years, and the constant agitation for change in curricula indicate the desire for something different. The new fact-finding and co-ordinating Board established by the Society aims to aid and direct progress

by co-ordinating the ideas of the various schools with those of industry and of the Engineering Profession.

It is not anticipated that a single general type of engineering school will be found adequate or desirable. Presumably, objectives and ideals will be more clearly defined, and each school will find, by self-determination, its own particular field. Its industrial environment, its type of students, its educational relations—whether part of a university or an independent school—its financial resources, its physical facilities, and its teaching equipment are all factors determining the service it can best render.

There are certain broad underlying questions on which the investigations should furnish data, among which are the following:

What class of subjects will best supply the cultural broadening outlook which technical courses lack?

Is the broader attitude of the student to be acquired through the non-technical so-called cultural subjects or through engineering teachers who have a larger conception of the relations of the engineer to society?

What differentiation should be made in the training of different types of men and in training for different fields of service?

Are the present faculties composed of men who have the technical knowledge and practical experience and teaching ability and the attitude toward life which adequately fit them for training the engineers of the future?

If not, what constitutes the ideal teacher and what measures should be taken to secure or to train engineering teachers?

Engineering societies can aid in specifying the ideal teacher, and can assist in finding him and inducing him to be a teacher. The engineering society may have more weight than the engineering faculty in giving boards of trustees a true vision of the relation of the engineer to society, which may result in wise selection and compensation of engineering teachers.

The rising cost of education in common schools, high schools, and colleges is discussed in the last report of the President of the Carnegie Foundation for Teaching. A large part of the great increase is attributed to new ideals regarding education, for example, that the school and college form a ready path to ease and prosperity with minimum effort, that every field of human knowledge must be included in the curriculum, and that vocational training even if it is superficial, must be given by the school. The engineering school is subject to the same tendencies, and a keen study of its objectives and purposes is a first essential in determining what it should do and the most efficient way of doing it.

The whole field is so large that the new Board must content itself with the initial selection of a few definite topics. The curriculum has been suggested as such a topic, not as a mere list of topics to embellish a page of the catalogue, but rather as the subjects which give character and content to engineering education. The first essential is a definite determination of the product the curriculum aims to produce. Furthermore, how is the curriculum to be administered? What type of teacher and what facilities are requisite? Broadly considered, a curriculum study may involve directly or indirectly many

of the apparently diversified questions of engineering education. An outstanding feature of the speaker's recent contacts with teachers, engineers, industrialists, and fathers of boys is the serious importance with which engineering education is discussed. It is not mere academic discussion. In a recent conversation regarding the new project of the Society for the Promotion of Engineering Education, the speaker stated that detailed plans had not been made, as a large part of the task is to formulate the problem, but what gives him inspiration and confidence is the large vision, the serious purpose, and the enthusiasm of the men of varied experience who constitute the new Board.

The Board is appreciative of this opportunity for a joint session of its Society with the American Society of Civil Engineers. It is most gratifying that the oldest of the National engineering societies is taking a part in engineering education. The weight of its counsel and advice will be welcomed by the Society for the Promotion of Engineering Education at large and by the engineering schools individually. The American Society of Civil Engineers has had a leading and conspicuous part in the engineering achievements of the past and present and now has opportunity to be an important factor in shaping and developing the engineers of the next generation. What is the vision of the Civil Engineer and the American Society of Civil Engineers as to the duties the engineer should assume in the next generation? This is a question of profound consequence to civil engineers, to all engineers, and to society at large.

THE OUTLOOK FOR THE ENGINEERING SCHOOLS OF THE MIDDLE WEST

By William G. Raymond,* M. Am. Soc. C. E.

The writer recently addressed a questionnaire to the deans of the engineering schools of the Middle West, including two foundation schools, the Northwestern and Washington Universities, and sixteen publicly supported schools. The questions asked were as follows:

1.—What has been your growth in total attendance in professional engineering courses for the first semester of the school years 1920-21; 1921-22; 1922-23?

2.—What has been the growth of the freshman class for the same period?

3.—Are the space, equipment, and teaching staff maintained in entirely satisfactory ratio to the attendance, or is either one of these items failing to grow sufficiently to give wholly satisfactory results?

4.—Is the preparation of entering students as a rule wholly satisfactory, or is there a noticeable deficiency in one or more lines, and, if so, in what line?

5.—Has the dropping of solid geometry and third semester algebra from general college entrance requirements produced any difficulty in handling first-year students presenting themselves for admission? If so, can you suggest a remedy?

Replies were received from the two foundation schools and twelve public schools.

Questions 1 and 2 were designed to secure replies that would indicate the outlook for attendance. Unfortunately, many people measure the worth of a school by the number of its students.

The Middle West is an agricultural district, and the farmer has been hard hit in this post-war period. His products were the first to drop in price to a pre-war level, and the prices of what he consumes have remained at a high level. As a result, the prediction was made in 1920 that college attendance in the Middle West would show a marked decrease, and that, perhaps, this would be particularly true of the attendance at engineering schools. The prediction has proved to be unwarranted. Most of the colleges are crowded beyond capacity with respect to space, equipment, and teaching staff.

The increase began prior to 1920, and the engineering schools and departments generally were crowded like the other branches. This was thought to be due to the advertising of the profession by its wonderful war service; but whatever the reason, the attendance at the engineering schools of the Middle West is greater than ever before, except during the first part of 1918-19, although a little less in 1922-23 than in 1921-22. The total attendance in the 14 schools answering the questionnaire for the beginning of the years given, was as follows:

1920-21	1921-22	1922-23
11 285	12 274	11 872

* Prof. of Eng.; Dean, Coll. of Applied Science, State Univ. of Iowa, Iowa City, Iowa.

The attendance in one of the largest schools is not included. The total attendance at the 18 schools is estimated to be about 15 000.

Perhaps of more significance is the registration of freshmen, as this is a better index of what the attendance of the next few years will be. The registration of freshmen in the 14 schools making returns has been:

1920-21	1921-22	1922-23
4 609	4 505	4 057

Therefore, although there was a larger total enrollment in 1921-22 than in 1920-21, and also a larger total enrollment in 1922-23 than in 1920-21, there was a decrease in freshman enrollment in both years, the enrollment this year being nearly 12% less than that of two years ago.

The peak permanent freshman class was that of 1919-20, when many high school students of 1917 and 1918, who had been in the Service, increased the regular class of 1919. This class will disappear in June, 1923, and, thereafter, a marked decrease in total attendance may be expected as a result of this disappearance and the presumable continued decrease in the entering class. Not all schools show a decrease in the entering class. In Iowa, both the schools have had a larger freshman class in 1922-23 than in 1921-22.

It may be said with some certainty that the immediate outlook for the engineering schools of the West, is for a smaller attendance. This outlook will not be displeasing to the directing officers of the schools, as in the majority of schools there will be relief from overcrowded conditions. Only four schools, two of which are foundation schools, reported adequate teaching staffs, space, and equipment.

The immediate outlook for maintenance of staff, space, and equipment in these agricultural States, the chief industry of which has been in great distress, is not good. It will be some time, apparently, before the schools reach an efficient basis, unless the combined effect of some additions to staff, space, and equipment, and a considerable reduction in attendance brings about that condition of balance toward which they are all striving.

The outlook with respect to character of work done in these Western schools is very good. Administration officers and faculties are studying contents of curricula and methods of teaching, and are inquiring into the needs of the profession with respect to two matters: First, the demand the employer with reason expects to make on the new graduate; and, second, the demand the public is making and is going to make in the future on the trained engineer of experience.

Perhaps it is beside the purpose of this paper to indicate what those who have made such inquiries have discovered or think they have discovered, but the risk will be taken and the statement made. It is believed to have been demonstrated by the replies to questionnaires sent to employers, by conversations with employers, and by printed statements that have appeared occasionally that the demand of the employer is for men thoroughly educated in the fundamental principles of engineering, and trained to reason correctly when using these principles. Employers seem to be aware that engineering schools are not trade schools, nor schools for the teaching of the details of the art of

engineering, such as schools of dentistry and medicine, which teach the details of the art of the practice as well as the science. The art of engineering is so extensive and varied and is so constantly changing in many branches that any person, whether he is a teacher or an employer, who is familiar with the work of the engineer must realize that, in four years of college work, it is impossible to teach both the fundamental theory on which the practicing engineer must rely for the development of his art, and also the details of that art, which to a considerable degree vary with each particular commission in which such art must be applied, if indeed it can be taught at all in college. Colleges of dentistry and medicine have their clinics and hospital practice, law schools their practice Courts, but engineering schools cannot build bridges, locomotives, railroad track, generators, telephone lines, etc., for the purpose of student practice.

The inquiring faculties think they have discovered, also, that the engineer is rapidly coming into what may be called "his own"; that the public is recognizing more and more the value of his advice on public enterprises—often not purely engineering enterprises. It is recognized that his training —narrow as it has been—and his professional experience, when it has been somewhat broader than his training, has fitted him peculiarly to reason correctly on economic questions as well as on questions of the technical application of the laws of physics, mathematics, and chemistry; and it seems to be more and more desirable that in college the young engineer should be trained somewhat in the fundamental principles of economics and accounting, and should have brought to his attention somewhat of the results of historic events.

The discovery or development of these things and one other circumstance have brought about the movement among the mid-Western schools for a more extended college training, "for those engineering students whose aim is to become qualified to take positions among the creative leaders in the profession."

The other circumstance is the poor preparation of the graduates of secondary schools in the Middle West. Possibly, this poor preparation is not peculiar to that territory, but certainly it is in evidence there whether or not it is in other parts of the United States. Almost all the engineering schools of the mid-Western States are supported by public funds, either State or Federal, or both, and the State University or the State College of Agriculture and Mechanic Arts is looked on as the head of the educational system of the State. It is expected, therefore, that these institutions will receive into their freshmen classes the graduates of any approved, four-year, high school, just as the high schools receive those who have finished the grammar schools, and the grammar schools receive those who have finished the elementary grades. Approval of a high school seems often to depend not so much on the character of the work done in it, as on the number of rooms, the number of teachers in proportion to students, and other considerations of this kind. Moreover, following the example of the colleges, there has been a distinct tendency in the high schools away from education and toward instruction, the difference between which terms has been defined recently.

In the mid-Western States there is an organization known as the North Central Association of Colleges and Secondary Schools, which defines subjects

acceptable for college entrance. The list has become so long that it is easy to find the necessary fifteen units without using either quadratic equations in algebra, solid geometry, or language other than English. There is in the State of Iowa, and perhaps in other States, an organization known as the Board on Secondary School Relations. This Board has abandoned what is commonly known as the third half year of algebra, which included quadratic equations, solid geometry, and languages other than English, as essential college entrance requirements. In this decision, the Board may have been acting under a real or imagined compulsion, as have some of the colleges in dropping these subjects. There is a tendency to try to make the secondary schools practical schools, supposedly training the greater number of their students for business life, because only the smaller proportion of their students expect to go to college. As the more advanced algebra and solid geometry have been abandoned as essential college entrance requirements, many of the high schools do not offer these subjects, and students who expect to go to engineering schools, all of which require these subjects as essentials to entrance to the first year, are not informed that they must cover these subjects, nor are they given opportunity to do so. They present themselves for admission to the engineering schools and are turned away or entered at a disadvantage, various unsatisfactory arrangements being made for their progress. Few of them complete their work in four years.

There seems to be a distinct tendency away from subjects that seem to be difficult, and from examinations to test the student's knowledge. It is somewhat difficult to locate the responsibility for these tendencies, and the speaker will not attempt to do so lest, in his ignorance and poor judgment, he should receive the condemnation of teachers' associations, and colleges and departments of education, which, it seems to him, have been yielding to a popular demand growing out of hastily formed erroneous ideas of the function of the school. Whatever the cause may be, however, it is certain that graduates of the average four-year high school of the mid-West are not prepared as they should be to enter a college of engineering that is attempting to give its students a proper training for their profession in four years.

The speaker does not know why the four-year college course was adopted rather than a three-year or a five-year course; but, at one time, when fewer principles of engineering practice were known, and when graduates of reputable high schools were better prepared in the fundamentals of mathematics, English, and other languages, than they seem to be at present, possibly due to the fact that there were fewer graduates from these schools, and only those who were especially adapted to scholastic work, four years of college training in engineering may have been sufficient. In those days, a course included more of general educational subjects such as history, foreign language, literature, and economics, than it does at present in the Middle West.

The members of the Society for the Promotion of Engineering Education know, and, perhaps, most of those who may read this paper know, that, having in mind all these points that have been mentioned, the deans of fourteen of the engineering schools of the Middle West assembled in Chicago, Ill., in May, 1922, to consider what should be done, particularly with respect to the length

of the college course in engineering. After discussing the matter for a day, they adopted a set of resolutions which, amended at a subsequent meeting in Urbana, Ill., are, as follows:

"The undersigned engineering deans, directors and representatives, in conference assembled, hereby resolve that,

"In order to meet the constantly enlarging responsibilities of the engineering profession, we favor an advance in engineering education at this time that shall provide five years of collegiate training for those engineering students whose aim is to become qualified to take positions among the creative leaders in the profession, and that such advance shall be made in substantial accordance with the following plan:

"1. Include in the four-year engineering curricula a substantial proportion of fundamental and humanistic subjects, omitting, if necessary, a sufficient amount of the more advanced technical work. It is desirable that, so far as possible the curricula in the different branches of engineering shall be sufficiently uniform to permit students to defer their final choice of a specialty at least to the end of the second year.

"2. Add a fifth year of advanced work, mostly or wholly technical, and specialized to such an extent as desired.

"3. The first four years of work shall lead to a bachelor's degree and the fifth year to an advance degree in engineering."

Re-assembling in June, 1922, at the time of the meeting of the Society for the Promotion of Engineering Education in Urbana, and after having been considered by the several faculties concerned in their respective schools, the resolutions, with a slight and unimportant amendment, were re-adopted as given and stand as the combined judgment of the immediate administrative officers of all these schools.

To resolve is one thing; to do is another; and in each school there are distinct difficulties in proceeding in accordance with the resolutions. There would be no difficulty except a financial one if all the schools would unite on an essentially common program, but each school is more or less afraid of the effect on its attendance of the adoption, by it alone, of a college course of five years. Unfortunate experience has been had by three of the mid-Western colleges in this respect. One of these is a foundation school and the other two are State supported schools.

It is believed, however, that the deans of these mid-Western schools are correct when they conclude that the broad, professional engineer, competent to design and to direct engineering enterprises of magnitude and to take his proper place in public affairs, cannot acquire the training in fundamental technical principles and an adequate knowledge of what may be called social science, even for a beginning in his life work, in four years of college training, after graduation from the average mid-Western secondary school.

There is some question as to how the five years or more shall be divided, whether two years shall be devoted to ordinary arts training, followed by three years or more of technical training in the engineering school, or whether the entire five years or more shall be within the engineering school, social and technical engineering subjects being carried side by side throughout the course with, perhaps, the final year devoted more particularly to the technical work of the engineer.

It is believed that the prevailing idea has been expressed by F. E. Turneaure, M. Am. Soc. C. E., in a letter* which states exactly the plan that is being considered most favorably by the faculty of the school with which the speaker is connected, and is thought to be that in the minds of most of the administrative officers who joined in the discussion at the meeting held in Chicago, in May, 1922.

Dean Turneaure's statement of the plan and the advantages that he sees for it are, as follows:

"In brief, this would consider a four-year engineering course (or pre-engineering course) which would be very general in its character. It would contain a large amount of work of general educational value, such as history, economics, language, science, chemistry, physics, mathematics, and mechanics, also the elements of applied work in the usual branches of engineering. Such a course I would consider the minimum requirement for any young man who desires to enter the industries or any field of engineering whatever; and for many lines of work it would be a satisfactory preparation. It would also furnish a sufficient foundation in mathematics and science to enable a man of real ability to advance himself in almost any line of engineering activity, even where a longer course of training would be preferable. By the elimination or postponement of a very considerable amount of technical studies now included in the regular four-year course, such a course as that indicated could be made quite satisfactory from the standpoint of general education, and, on the whole, much more satisfactory than a four-year course in a college of liberal arts, such as would be elected by students planning on an engineering course later. At least, it would meet the needs of a great many more students, and I am inclined to think that it would be the best course for practically all.

"The four-year course as indicated should lead to a degree (such as the B. S. degree), without special designation. Then those students who desire a more thorough engineering education should secure it by further study, either in the form of graduate work or fifth and sixth-year courses leading to an appropriate second degree. These advanced courses would be well organized, and would be taken by a very considerable number of students, as they would contain a good share of the material now included in our senior year. They would naturally be taken by all students desiring to enter the research field and those aiming to become fairly well posted in any special line. I should suppose that from 25 to 40% of those finishing the four-year course would continue for a fifth or sixth year, the percentage depending, of course, quite largely upon the curriculum adopted.

"Among the advantages of such a scheme as above suggested are possibly the following:

"1. It requires all engineering students to secure a much broader general education than is now the case, while at the same time it includes a sufficient amount of fundamental technical work to satisfy the requirements in many cases.

"2. It furnishes the well-organized technical work for special and advanced students which will encourage students of ability to thoroughly prepare themselves for research and special work of various kinds. Graduate courses in engineering will be much better organized than is now the case.

"3. It is a better arrangement than that frequently proposed of requiring a two- or three- or four-year college course before admission to the engineering school. In any pre-engineering course, a considerable amount of mathematics and science must be required in order to save time, and pre-engineering courses

* *Engineering Education*, December, 1922.

under the control and advice of the engineering faculty can be better adjusted to the students' need than when otherwise administered.

"4. It would, I believe, solve the problem of the four-year course, against which so much criticism is directed.

"5. It would tend to eliminate from the more advanced and technical work students who are unfitted for such work while at the same time capable of becoming successful engineers in certain lines of employment. With the very great numbers now attending engineering schools, a relief of work in the senior and junior laboratories would be very acceptable in most cases."

It is believed that the attitude of the schools of the mid-West is shown in the preceding discussion and indicates an extremely good outlook for the character of the work to be done, in reading the signs of the times aright, and in adapting the work to changing standards and requirements for the trained engineer.

Engineering research is being developed with considerable rapidity in a great many schools. There are those who say that the primary function of a university is research, that its teaching work is incidental. It is believed that, except with respect to those institutions created primarily for research, such a statement is wide of the fact, and, with respect to the State universities of the Western and Southern States, it is certainly not in accordance with the ideas in the minds of those who created those institutions.

Standing as the capstones of the educational systems of the States, the State universities were created primarily to give what was commonly known as a college education to the youth of those States. Research was hardly thought of by any one connected with the institutions when they were created. In connection with these institutions, this idea is of modern growth.

Research is an important function of a university, and it may be, but is not necessarily, an important function of an engineering school. It is believed to be fair to state, however, that those schools in which engineering research of importance is being developed, are schools in which the students even though they do not participate in research work, are brought into an atmosphere that is wholly beneficial; and it is also fair to state that, in the engineering schools in the West, research is being developed with some rapidity.

It has been impossible for the speaker to learn and record, with any accurate detail, the research activities of the several schools; but many are probably familiar with certain outstanding work accomplished at some of the schools, such as the work of the great Forest Products Laboratory at one school; the experiments in sanitation and the investigation of numerous railroad, mechanical, and fuel questions in another institution; investigation of the strength of drainage tile and pressure of earth in trenches on such tile, and certain questions of interest to highway engineers, in another institution; and elaborate, large scale, experiments to determine the extent to which the hydraulic jump may be utilized, at still another institution, favored with a river of considerable size flowing through its campus, are all reasonably well known to the Engineering Profession. These activities in engineering research are positive indications of the advancement of the engineering school faculties of the West. As a result of the development of research work, there

is a considerable registration of graduate students engaged in advance work related to this research.

The proposal that has been made that these institutions correlate their work so that each will engage in those lines of research for which it may be peculiarly adapted, or prepared already, and duplication of effort avoided, would seem to be another indication of advancement.

On the whole, therefore, a consideration of what has been said would seem to warrant the conclusion that the outlook for the engineering schools of the Middle West is an extremely favorable one; that the ratio of equipment and teaching staff to attendance—although at present unfavorable—is tending to become more and more favorable by the reduced attendance and increased facilities; that the character of the work done in the schools, always good, is constantly improving; that they are adapting themselves to changing standards and requirements for the trained engineer; and that they are developing with some rapidity that important function of research, which is enabling them to add in no small degree to the already accumulated store of professional knowledge.

CO-OPERATION OF NATIONAL ENGINEERING SOCIETIES IN ENGINEERING EDUCATION

By John L. Harrington,* M. Am. Soc. C. E.

Engineering education and the possibilities of co-operation by the engineering societies in the solution of its problems is too broad a subject for rounded discussion in the time allotted. Therefore, consideration will be limited to one phase only, namely, the direct relation of the National Engineering Societies to the students as it finds expression in the establishment and conduct of Student Branches.

The practicing engineer has always considered it to be his function to point out the shortcomings of the engineering schools and to criticise the curriculum, the work of the faculty, and the delinquencies of the students. As an employer of the product of the schools, his assumption of this function is not without warrant, and insofar as his criticism has been constructive, it has been helpful; but too commonly the practitioner has looked on the student, not as his successor, but as his tool, and has decried his imperfections and scolded the faculty for permitting them. He has demanded a finished product, men thoroughly trained and ready to do work of high commercial value, men of direct and immediate service to him.

The engineering student has commonly held somewhat the same view. He has demanded strictly technical, directly useful knowledge and has been impatient with the collateral subjects essential to the broad foundation required for ultimate achievement of a high character. As new engineering schools were established and competition for students was increased, it is small wonder that the faculty bowed to the demand of the student and the practitioner alike and filled the curriculum with technical studies to the exclusion of all but the most essential preparatory subjects.

The result has been that the schools have turned out men of increasingly narrow training as specialized knowledge accumulated. Forty or fifty years ago, civil engineering included all but military engineering, and technical subjects were so few and so little developed that many academic subjects were necessarily included to fill out the year's course generally considered essential for sufficient mental training. For many years, however, the number of technical subjects and the demand for them have been so great that the curriculum has been divided into civil, mechanical, electrical, and chemical engineering, and even these branches have many sub-divisions, so that a graduate has not only little cultural education, but is without satisfactory knowledge of the fundamental sciences which support the technical work.

In like manner, engineers engaged in certain branches of technical work became impatient with the necessity for considering the problems of those engaged in other lines, developed a high degree of pride in their specialty, and organized separate societies of increasingly narrow purposes. Often the objects of the society were so restricted that the number of its members was

* Cons. Engr., Kansas City, Mo.

insufficient for effective operation; and as it is exceedingly difficult to make clear divisions, the activities of many organizations overlap. This has compelled the individual to maintain membership in several societies in order to sustain close contact with all his interests.

In recent years, as the professional engineer has become dissatisfied with his place in the world and has come to resent the fame and fortune accruing to the lawyer, the promoter, or the business man who made use of his technical knowledge while he remained in the background, he has slackened his demand for strictly technical training and is now urging more education in those branches which will enable him to make complete use of his technical knowledge, to build on it administrative and executive functions which formerly were considered beyond his province. This breadth of view, however, is so recently established that his earlier habit of segregation and specialization still dominates his mind to such an extent that he fosters the interests of his special group to the hurt of his profession.

Increasing professional consciousness has steadily increased interest in the training for the profession, and the engineering societies, stimulated by their members in the universities, have not only concerned themselves with the character of the curricula of the engineering schools, but have sought by establishing student branches to help the student directly to an understanding of the work, the ethics, and the ideals of the engineer, and to further his development after graduation by leading him to join the society devoted to his specialty. These purposes, both worthy, are not entirely altruistic, for the societies profit by the readier transition on graduation from membership in the student branch to membership in the society; but to the credit of the societies it must be admitted that this purpose is secondary.

The best of purposes are, however, sometimes mistaken. In considering the benefits, the evils escape attention. The operation is successful, but the patient remains an invalid or even dies. So it is in this instance.

A thorough survey of the condition of the student branches made in 1922 by Dr. William H. Kennerson, Dean of the School of Engineering of Brown University, in the course of which he visited branches in all parts of the United States, compelled him to conclude that most student branches were sustained by artificial respiration administered by interested members of the faculty. His report discourages the thought that the student branch is accomplishing the purposes for which it was formed, and an analysis of the matter will clearly disclose the reasons.

In all co-operative effort the benefits received are substantially proportional to the efforts put forth, and as the student branches are organized by the society and kept alive by the faculty, the student's activities are limited and his benefits are proportionately small. In some cases, competent student leaders secure worthy results, but, generally, the student is already surfeited with the leadership and direction of others and his interest is small where the initiative and control are not his own.

Not only are the student branches failing measurably to serve the purpose for which they were organized, but they are doing their members a great injury. It is generally agreed that the training of the engineer is much too

narrow, that, in addition to a certain amount of technical knowledge, supported only by the absolutely essential mathematics and the barest elements of the directly related sciences which now constitute his training, it should include a superior command of English and of at least one other language, sounder training in chemistry, metallurgy, and physics, and a substantial knowledge of history, literature, logic, psychology, economics, accounting, geology, mineralogy, and other subjects essential to the support of the technical work and to the broad training of a truly professional man. It is well understood that the engineer especially needs training in the science of politics, in understanding, organizing, and controlling men; yet, in establishing and fostering student branches, each little group is set off by itself, and its interests are restricted to only one branch of engineering and to its own members.

The eminent engineer with the broad message of interest is no longer invited to deliberate to all the students of an engineering school, but to one division of them, to a student branch; or, if his message is technical, only those studying his specialty hears it. This results in greater difficulty in securing the interest of able men who are unwilling to take the time to serve a minor group, and, manifestly, it results in restricting the knowledge and narrowing the vision of the students.

Both the students and the societies would be better served, and energy, effort, and funds would be conserved, if the four Founder Societies could agree on a plan of cordial co-operation in educating and training the future members of the profession. The Honorary Engineering Society, Tau Beta Pi, offers an excellent example for a society composed of engineering students of all kinds, having a chapter in each of the engineering schools and supervised by a council of four, one to be elected each year by the delegates from the chapters in convention. Each member of the council should serve through four years and should be selected rotatively from lists submitted to the convention by the respective National Societies. Each student chapter should be advised, but not governed, by suitable members of the faculty, but the actual management should be in the hands of the students who would have the initiative and who would thus be trained for future activities in the professional societies. The close association in each chapter of students of all branches of engineering, the acquaintance of all with the publications of all the Founder Societies, the meeting of all together when an address is to be delivered, the presence of all when any engineering matter is under discussion, and the interest in the chapter of all members of the engineering faculty, will broaden the student's knowledge of the profession, will teach him to work in harmony with those whose interests and views differ from his own, and will strengthen him in every way for the battle which follows graduation. Institutions having one or more groups too small to be organized into a student branch may well secure a chapter of such a co-operative society to the distinct benefit of both the students and of the Founder Societies, and each student will become so well acquainted with every branch of the profession that he will choose from among them with greater certainty of his fitness for the work of his choice. Every one is familiar with failures resulting from errors

in selecting a vocation arising from lack of knowledge of other vocations. The drafting rooms of the larger engineering works contain many technically trained men who have failed to accomplish according to their abilities, because of error in the choice of work. Selection of a specialty to-day is largely a matter of whim or chance, not of knowledge of the field.

A recent writer discussing the purposes of the students has stated:

"I have known hundreds, thousands of undergraduates, but I cannot think of one who has a clear idea of why he has come to college. I hasten to make two exceptions. Engineering students know that they come to learn to be engineers, but they know that they must learn something more than that—and they do not know what that extra something is."

What are the National Societies doing to help solve the problem? Are their divided and inharmonious endeavors helping? Does it broaden the student, make him wiser and more tolerant, to see his elders in the profession carrying their differences of organization and opinion down into the kindergarten of professional training?

There is no substantial reason, no reason that a broad-visioned man can reasonably give, why the Founder Societies cannot wholeheartedly co-operate in carrying to the student the lesson and the support they have for him. For several years, they have been making an energetic endeavor to co-operate in rendering disinterested service to the nation, in bringing to bear on the public affairs in which they are peculiarly fitted to serve, the united strength of the profession. Such large bodies move slowly, but with great effect once they are in motion; but before they can materially swerve the views of others, they must show their own ability to accept the truth, to sacrifice something of the individual interest for the general good. Let us stop the discord at its source and bring the engineers of the next generation under greater harmony of thought and action than we have been able to achieve, by uniting in a common effort to broaden and train them for a unified service to the profession and to the world.

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TECHNICAL PAPERS
PRESENTED AT THE ANNUAL MEETING,
JANUARY 19, 1923

ENGINEERING RESEARCH

THE RESEARCH ACTIVITIES OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

By Arthur N. Talbot,* Past-President, Am. Soc. C. E.

Engineering art is based on a variety of things, ingenuity, experience, judgment, rules and regulations (even rule-of-thumb), precedent, vision, the laws of Nature known as physics and chemistry, and the special applications and adaptations of the laws known as engineering science. In the early days of engineering, ingenuity, experience, and judgment, were the dominating influences, and engineering science played a minor rôle. As time went on and experience grew, rules and regulations became more important. The increasing magnitude and difficulties of engineering projects, the need for greater permanency, economy, and safety, and the varying and diversified nature of engineering work, brought forward the importance of basing engineering art more fully on engineering science. The physical sciences grew, giving greater opportunities to the engineer; and, conversely, the wonderful development of engineering stimulated the development of both pure and applied science. Altogether, the growth and development of engineering in the past generation has been wonderful. It will not be overlooked by any one that engineering must continue to need ingenuity, experience, and judgment, and rules, precedent, and vision, but more and more, as time goes on, will it be dependent on science and that accumulation of applied science which may be grouped under the term, engineering science.

The growth of a science is not spontaneous; the fruit of engineering science is dependent on well-directed effort, the expenditure of time, energy, and money, and this fact should always be borne in mind. The instrumentalities that are available for the investigation of engineering topics are much the same as those which are useful in the development of other lines of applied science. The industries have their laboratories, some for private and, perhaps, selfish ends, some which give out results generously to the profession and the public or even co-operate openly with public agencies. The railroads have done much in engineering research. Private laboratories are contributing to the fund of knowledge. The Federal and State bureaus and departments are continuing to give valuable contributions to engineering knowledge, as instanced by the work of the U. S. Bureau of Standards in cement, concrete, and structural materials, that of the U. S. Bureau of Public Roads in soils, road materials, and road construction, and that of some of the States in road construction and maintenance. The laboratories of engineering schools all over the United States are conducting considerable engineering investigation in a promising way, some through organizations called engineering experiment stations, others in less formal ways. A recent report of the organization of Landgrant Colleges enumerated more than one hundred researches now in progress in the engineering departments of those colleges, nearly all of which have some

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application to civil engineering operations. Many schools that are not active in engineering experimentation at present would be pleased to have the opportunity to utilize their laboratory equipment for some productive work. It is evident that, as the years go on, the engineering college will take an increasingly active part in research. Finally, the engineering society may be named as one of the instrumentalities from which development of engineering science should be expected.

To quote from a former address,* a National engineering society should be (among other things), "a collector and disseminator of engineering knowledge; a forum for the discussion of engineering questions, simple and complex, small and large; a stimulator of research and of the progress of engineering science; a developer of engineering methods and practice", * * *. Is not being "a stimulator of research and of the progress of engineering science" an important function of an engineering society which has for its object the advancement of the science of engineering in the several branches? Is it not within the province of the engineering society to promote the conduct of research, to assist and co-operate in its extension, and even to participate in its activities? Its members know the needs of the profession, can forecast to a considerable degree the trend of engineering development, and should be able to outline, direct, study, and interpret investigational work; and such work may be expected to furnish contributions to engineering knowledge that will add greatly to the advancement of engineering art.

Many of the engineering societies have participated freely in research activities. The American Society of Mechanical Engineers has had a Committee on Research for years and has made important contributions to engineering science. Its monthly journal has a well-conducted department which digests and reports the available results of research applicable to mechanical engineering. The American Society for Testing Materials has long been a most important instrumentality for organizing, stimulating, and reporting engineering research; it has secured the hearty co-operation of both industries and institutions, and its volumes are replete with valuable contributions. The American Railway Engineering Association has likewise contributed much to engineering science, through laboratory, field, and office investigation. Reference should be made to another instrumentality, closely allied to the four Founder Societies, Engineering Foundation, largely the conception of Ambrose Swasey, Hon. M. Am. Soc. C. E., who generously started its endowment "for the furtherance of engineering, for the advancement of the profession and the good of mankind". Engineering Foundation has worked to encourage, direct, and develop research agencies and activities and, at the same time, give such financial aid to research work as has been found practicable. The Division of Engineering of the National Research Council, an organization formed during the World War and now operated for the purpose of securing the co-operation of engineering agencies in which research facilities are available, has continued to be very active. Its Advisory Board for Highway Research has been conducting important engineering researches. The work of all these organizations may be classed under engineering society activities.

* *Transactions*, Am. Soc. C. E., Vol. LXXXIII (1919–20), p. 416.

The American Society of Civil Engineers has a large amount of engineering research to its credit, although it has not had an aggressive research policy. The *Transactions* contain a large number of individual research contributions, many of them of the highest value. One need only call attention to the paper on "Experiments Relating to Hydraulics of Fire Streams",* by John R. Freeman, Past-President, Am. Soc. C. E., that on "Experiments at Detroit, Mich., on the Effect of Curvature upon the Flow of Water in Pipes",† by Gardner S. Williams, Clarence W. Hubbell, and George H. Fenkell, Members, Am. Soc. C. E., and that on "The Economical Design of Reinforced Concrete Floor Systems for Fire-Resisting Structures",‡ by John S. Sewell, M. Am. Soc. C. E., to illustrate the quality of these personal contributions. The rules of the Norman Medal provide that "the medal shall be awarded to a paper which shall be judged worthy of special commendation for its merit as a contribution to engineering science", and the rules of the J. James R. Croes Medal and the James Laurie Prize recognize the usefulness of contributions to engineering science. The lists of awards are full of papers giving reports of scientific researches, both experimental and analytical, and the *Transactions* contain very many more that were not recognized in this way.

Many of the special committees which have been appointed throughout the life of the Society have reported research information of value. The report§ of the Special Committee on Uniform Tests of Cement gives experimental information which was of great interest and helped to establish standards which have proved to be very useful to the Engineering Profession. Other committees, like the Joint Committee on Concrete and Reinforced Concrete‖ reporting in 1916, conducted tests on which to base parts of its recommendations. The Special Committee on Steel Columns and Struts¶ carried on an elaborate set of tests of columns and reported results of much value. In later times, the Special Committee to Report on the Bearing Value of Soils for Foundations, etc., which is still continuing its work, has carried on considerable experimental work. The Special Committee to Report on Stresses in Railroad Track, formed in 1914, has conducted experimental work on a large scale and has now presented its third formal progress report.** The three reports contain a great deal of information on the action of the track structure, which is considered very valuable by railroad men. It should be added that this Committee has been co-operating with the American Railway Engineering Association and the American Railway Association.

Altogether, it is evident that the papers of the Society and the activities of its meetings and committees include contributions to engineering science, which have exercised an important influence in the development of engineering art, and that the Society has been an effective instrumentality in the extension and development of engineering science.

* *Transactions*, Am. Soc. C. E., Vol. XXI (1889), p. 303.

† *Loc. cit.*, Vol. XLVII (1902), p. 1.

‡ *Loc. cit.*, Vol. LVI (1906), p. 252.

§ *Loc. cit.*, Vol., LXXV (1912), p. 665.

‖ *Loc. cit.*, Vol. LXXXI (1917), p. 1101.

¶ *Loc. cit.*, Vol. LXXXIII (1919–20), p. 1583.

** See p. 295.

For the purpose of formulating and conducting a more active and systematic research policy, the Board of Direction has created a Committee on Research. The minutes* of the meetings of the Board of Direction of January 18 and March 8, 1921, give the following three actions in creating this Committee and defining the scope of its work, according to recommendations made by a special committee of the Board:

"That a Committee on Research be appointed which shall consider and deal with matters of research which may be taken up by the Society and which shall make recommendations concerning research that in its judgment should be taken up by the Society—whether the research work be undertaken by the Society, or be done in co-operation with other societies and committees, or be promoted or stimulated by the Society."

* * * * * * *

"That the Committee on Research and the representatives of the Society on the Advisory Committee be not restricted to members of the Board of Direction and that the element of reasonable continuity of membership be accepted as desirable."

* * * * * * *

"The duties of the Committee on Research (to consist of seven or nine members) shall be to organize, stimulate, and supervise the research work of the Society as conducted by its Committees or through co-operation with societies and individuals, in accordance with the direction and regulations of the Board of Direction."

It will be seen that the Board of Direction had in contemplation plans for co-operation and the stimulation of activities in engineering research.

At the meeting of the Board of Direction of January 18, 1921, the same special committee reported on the letter† of Dr. C. A. Adams, Chairman of the Division of Engineering of the National Research Council, inviting the Society to become the Sponsor Society in research work in Civil Engineering, and to appoint representatives on the Advisory Committee on Civil Engineering. The following extracts‡ will indicate the nature of the reports:

"The Committee has given consideration to the project and to possible relations to research activities of the Society. It feels that research work in engineering should be promoted by the Society in such ways and to such extent as seem practicable for the Society to undertake. The proposal to co-operate with the National Research Council seems a promising method of stimulating and advancing engineering research. An acceptance of the invitation, however, should not be permitted to involve interference with the right or duty of the Society to advance or carry on research work on its own account or in co-operation with other societies or bodies. The Committee believes that the Society should maintain a cordial interest in stimulating and advancing the progress of engineering science and that it has a duty toward this side of engineering. With a view of safeguarding and stimulating this function of the Society and at the same time co-operating with the National Research Council, the Committee proposes the following:

"That the Board of Direction accept the invitation of the Division of Engineering of the National Research Council to become the Sponsor Society in research work in civil engineering and to appoint representatives on the

* *Proceedings*, Am. Soc. C. E., February, 1921, pp. 168–169, and April, 1921, p. 384.

† *Loc. cit.*, December, 1920, p. 917.

‡ *Loc. cit.*, February, 1921, pp. 168–169, and April 1921, p. 384.

Advisory Committee on Civil Engineering of the National Research Council and to accept other responsibilities connected therewith."

* * * * * * *

"The duties of the representatives of the Society on the Advisory Committee on Civil Engineering of the Division of Engineering of the National Research Council shall be to represent the Society in its responsibilities therein as Sponsor Society in research work in civil engineering, in accordance with the directions and regulations of the Board of Direction. The representatives of this Society on this Advisory Committee shall be not more than fifteen, and shall include the Committee on Research of the Society."

This Advisory Committee was appointed subsequently, and is now called the Advisory Board on Civil Engineering Research.

The Committee on Research was organized on January 18, 1922, with the speaker as Chairman and F. E. Schmitt, M. Am. Soc. C. E., as Secretary. In the following months, discussion was had through correspondence on the division of the field and on what work should be undertaken first. Further discussion was had and action was taken at the meetings of the Committee at Dayton, Ohio, on April 4th, and 5th, 1922, and recommendation* was made to the Board of Direction for the creation of research committees, as follows: Stresses in Structural Steel; Irrigation Hydraulics; Hydraulics Phenomena; Impact in Highway Bridges; and Flood Protection Data.

The Board of Direction at its meeting of April 4, 1922, approved these recommendations and the committees were later appointed and have been actively at work with the exception of the Committee on Hydraulics Phenomena which has not yet been appointed. Progress reports were made by these Committees at the Annual Meeting on January 17th, 1923. It may be of interest to note that the Committee on Stresses in Structural Steel was instructed to limit its activities as follows:

"This Committee should be instructed to limit its activities at the present time to an investigation of the properties of commercial structural steel (both mill and stock material) as bearing on the problem of what working stresses should be allowed for steel building construction, and to report to the Board of Direction on the feasibility of conducting extensive measurements of stress distribution in structural frame work other than bridges."

At the meeting of the Board of Direction on January 16, 1923, the recommendation of the Committee on Research for the appointment of a Committee on Reinforced Concrete Arches and a Committee on Steel Column Research was adopted, and it is expected that these committees will be appointed in the near future.

The Committee on Research has discussed the needs for research work in the various fields of civil engineering. The number and variety of the topics that call for investigation will convince any one of the richness of the prospect and the wealth of opportunity for service. As new technical divisions of the Society are organized, new demands will appear. Sanitary engineering, power, railways, highways, structural steel, concrete, engineering materials, and many other fields, all have their problems. The difficulty lies not in finding the problems, but in selecting those that are the most pressing, the easiest of

* *Proceedings*, Am. Soc. C. E., May, 1922, p. 390.

solution, or have the most willing workers. Many topics have been suggested. It has seemed the wise policy not to extend committee work too rapidly, but rather to support and assist the work of the committees now appointed, and to constitute others only as fast as conditions seem to warrant. It is clear to the Committee on Research, however, that there are many fields and a large number of topics that should be investigated by the Society, both by itself and in co-operation with other organizations. It is felt that as time goes on the Society should actively develop the policy of stimulating research in all the branches of civil engineering and of contributing to engineering science in every reasonable way.

The securing of funds to support research may seem a troublesome question. The increasing "high cost of living" has made the income of the Society scarcely equal to its needs, with little chance for expansion in service. In many problems, however, the necessary expenditures will be small. In other cases, after the problem has been outlined, engineers will willingly aid in carrying out the work. In still others, governmental agencies or industrial organizations will be found willing to co-operate. In still others, sums may be raised by subscription from corporations and individuals. The contributions for the work of the Joint Committee on Stresses in Railroad Track may encourage the Society in bringing other research problems to the attention of those who may appreciate the value of a thorough investigation. Engineering Foundation will doubtless contribute as freely as its resources and its other demands will permit. It is to be hoped that its funds will be greatly augmented by new and princely gifts. The Society itself may be expected to contribute in various ways. Its practice now is to pay mileage for attendance on committee meetings. It would seem proper, however, to do more than this—to contribute something to some classes of research that may not appeal to the outside contributor, to do a little, too, in other ways, as an earnest of its interest and faith in the value of such work. This help may not be given at once, but it would seem that the Society should shape its expenditures so as to set aside for the use of research work, as time goes on, a moderate sum for this particular function of the engineering society.

The conduct of committee research work itself, however, will involve time and labor, in conducting the tests, in studying and digesting the data, and in interpreting the results and presenting the findings in an acceptable way, even tedious, dreary, fatiguing hours and days. The men who undertake the work will do it cheerfully, as becomes those who aspire to help in extending the bounds of knowledge, and will find compensation therefor in the satisfaction that they have thereby done some small part in contributing to the advancement of the profession of engineering. They should know that the membership of the Society is in a receptive mood and will commend their contribution to engineering science.

In conclusion, it may be well to state that the Committee on Research will welcome suggestions and constructive proposals. It asks for assistance in every way. May not the Society gain greatly by the co-operation of many in these lines of endeavor?

ENGINEERING FOUNDATION: DIVISION OF ENGINEERING, OF NATIONAL RESEARCH COUNCIL: THEIR ORIGIN, WORK, PLANS, NEEDS

By Alfred D. Flinn,* M. Am. Soc. C. E.

In 1914, the spirit of progress and service among engineers found another expression through the farsight and generosity of Ambrose Swasey, Hon. M., Am. Soc. C. E., in his gift of $200 000 to United Engineering Society to be the nucleus of a great endowment "for the furtherance of research in science and in engineering, or for the advancement in any other manner of the profession of engineering and the good of mankind." With this gift as a corner-stone, there is being erected under the auspices of the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers and the American Institute of Electrical Engineers, an institution known as Engineering Foundation, devoted primarily to conducting and furthering researches and investigations in applications of science to engineering and its related industries. Subsequently, Mr. Swasey increased his gifts to a total of $500 000, yielding an annual income of $26 000.

United Engineering Society is the legal owner of the principal of Engineering Foundation's Endowment Fund. This Society is in effect a board of trustees incorporated under New York State laws "to advance the engineering arts and sciences in all their branches, and to maintain a free public engineering library", with power and authority "to receive, conserve, invest, and reinvest, hold in trust, and administer such moneys or other property as it may receive from any source for its own purposes or for any other endowment or activity within the scope of its charter." This Society has twelve members, three chosen by each Founder Society. It has now two departments: The Engineering Societies Library and Engineering Foundation. Engineering Council was a third department from April, 1917, to December, 1920. United Engineering Society owns and administers for the Founder Societies, Engineering Societies Building and Library and several permanent funds.

The legal status of Engineering Foundation Board is that of a committee of United Engineering Society. The Foundation has full discretion in the expenditure of the income from the Endowment Fund and such other moneys as may be given to it, or to United Engineering Society for it, for research and other projects. The Foundation has sixteen members, elected by United Engineering Society—one trustee representing each Founder Society, two members from each Founder Society nominated by its governing body, who are not trustees, three members at large, and the President of United Engineering Society *ex officio*. Its officers are Charles F. Rand, Chairman, Edward Dean Adams, F. Am. Soc. C. E., and Frank B. Jewett, Vice-Chairmen, with two other members, George H. Pegram, Past-President, Am. Soc. C. E., and H. Hobart Porter, M. Am. Soc. C. E., constituting its Executive Committee.

* Director, Engineering Foundation, and Chairman, Division of Engineering, National Research Council.

The Treasurer and Assistant Treasurer and the Counsel of United Engineering Society *ex officio* function for Engineering Foundation. The Director of the Foundation is also its Secretary. The Foundation has offices in Engineering Societies Building, which are provided by United Engineering Society.

Engineering Foundation, therefore, is not an outside, independent institution, but is an integral part of the organism of the Founder Societies and of each one individually, as the Library is. It was created by them on the basis of Mr. Swasey's gifts, should have their continuing support, and should be utilized by them. It is their joint instrumentality for research and investigation, especially for such projects as involve more than one branch of engineering and science as do most researches and investigations of interest to engineers. As its resources are increased, its service can be greatly extended.

In 1916, National Research Council was created at the request of the President of the United States, by joint action of the National Academy of Sciences, National Engineering Societies, and Scientific Associations. It became, in 1917, the Division of Science and Technology of the Council of National Defense. Necessarily, it had a Committee on Engineering, with a number of sub-committees, which did notable service during the World War. National Research Council is based on the charter of the National Academy of Sciences given by Act of Congress in 1863 and signed by President Lincoln. Its legal status is that of a committee of the Academy. It was perpetuated by the Executive Order issued by President Wilson on May 11, 1918, which, among its provisions, directs the heads of Governmental departments to co-operate in every way required. Therefore, although the Council is not a Governmental bureau, it has intimate relations with the Federal Government. Except for war purposes, the Government has provided no funds for its support. All its financial resources come from private institutions and individuals, except to the extent that Governmental bureaus participate in research projects of interest to them. Largest among the gifts are $5 000 000 from the Carnegie Corporation of New York for a building and endowment; $500 000 from the Rockefeller Foundation for research fellowships in physics and chemistry; and $500 000 from the Rockefeller Foundation and the General Education Board equally for research fellowships in the medical sciences. About $1 330 000 are being expended on a permanent building near the Lincoln Memorial, in Washington, D. C., to be ready for occupancy in the fall of 1923.

Engineering Foundation had an important part in the establishment of the National Research Council. When organized, the Council had neither funds nor office. The Foundation at once placed at its disposal offices in Engineering Societies Building and the entire income of the Foundation fund for a year, supplemented by special gifts, together with the services of a Secretary. As soon as practicable after the armistice, National Research Council brought its war projects to a conclusion or made other disposal of them and created a tentative form of organization better suited to peace conditions, having thirteen divisions. There are six Divisions of General Relations, as follows: Government Division; Division of Foreign Relations; Division of States Relations; Division of Educational Relations; Division of Industrial Relations; and Research Information Service.

There are also seven Divisions of Science and Technology, as follows: Division of Physical Sciences; Division of Engineering; Division of Chemistry and Chemical Technology; Division of Geology and Geography; Division of Medical Sciences; Division of Biology and Agriculture; and Division of Anthropology and Psychology.

After three years' experience in an untrodden field, National Research Council is re-studying this form of organization, seeking greater economy and effectiveness.

From the beginning, cordial co-operation has been maintained between Engineering Foundation and the National Research Council. The Secretary of each has been, by reciprocal arrangement, an Honorary Assistant Secretary of the other, the Secretary of the Foundation being thus a member of the Executive Board of the Council. Likewise, there has been exchange of office accommodations in New York City and Washington. Since the establishment of the Division of Engineering in March, 1919, it has been closely related to Engineering Foundation and since October of that year, the Foundation has provided offices in Engineering Societies Building for the Division, and a substantial portion of its funds. Measured on the financial basis, the work of the Division has been about 40% an activity of Engineering Foundation. In addition, the Foundation has contributed funds and services to a number of the research projects of the Division, besides undertaking other projects jointly with it. A certain number of members of the Foundation are, by definite arrangement, members of the Division. From October 1, 1920, to October 1, 1921, the Secretary of the Foundation was also a Vice-Chairman of the Division, and since October 1, 1921, he has been its Chairman.

The Division of Engineering formally states its objects to be: To encourage, initiate, organize, and co-ordinate fundamental and engineering research and to serve as a clearing house for research information in the field of engineering. Its total membership is 40, of which 21 are representatives from 14 National engineering societies, and one a liaison member of the Division of Federal Relations, and 18 members at large. In membership, it is more catholic than Engineering Foundation, since to the Founder Societies it has added ten other societies dealing with important engineering specialties. The work of the Division is conducted by its Chairman and Secretary, who are paid officers, a Vice-Chairman, and an Executive Committee having four additional members. There are four Advisory Boards, each dealing with a broad field of engineering, and four boards and 14 committees, advising in limited fields or conducting research projects under the supervision of the staff of the Division.

The scope and importance of the work of the Division of Engineering, in which Engineering Foundation has so large a share, cannot be indicated briefly better than by the following list of the titles of its boards and committees:

Advisory Board on Civil Engineering Research, Robert E. Horton, M. Am. Soc. C. E., Chairman, sponsored by the American Society of Civil Engineers.

Advisory Board on Mining and Metallurgical Engineering Research, sponsored by the American Institute of Mining and Metallurgical Engineers.

Advisory Board on Mechanical Engineering Research, Walter Rautenstrauch, Chairman, sponsored by the American Society of Mechanical Engineers.

Advisory Board on Electrical Engineering Research, John B. Whitehead, Chairman, sponsored by the American Institute of Electrical Engineers.

Advisory Board on Testing Materials; the Executive Committee of the American Society for Testing Materials, George K. Burgess, Chairman.

Advisory Board on Illuminating Engineering Research; the Research Committee of the Illuminating Engineering Society, Edward P. Hyde, Chairman.

American Bureau of Welding, Comfort A. Adams, Director, sponsored by the American Welding Society. Committees on Electric Arc Welding, Welding Conference, Welding of Storage Tanks, Welding Wire Specifications, Standard Tests for Welds, Training of Operators, Specifications for Steel to be Welded, Resistance Welding, Thermit Welding, Welded Rail Joint Committee, Pressure Vessels.

Advisory Board on Highway Research, A. N. Johnson, M. Am. Soc. C. E., Chairman, W. K. Hatt, M. Am. Soc. C. E., Director. Committees on Character and Use of Road Materials, Economic Theory of Highway Improvement, Tractive Resistance of Roads, Structural Design of Roads, Maintenance, Highway Finances, Highway Traffic Analysis.

Committee on Deoxidizers, George K. Burgess, Chairman, J. R. Cain, Research Metallurgist.

Committee on Electrical Core Losses, A. E. Kennelly, Chairman.

Committee on Electrical Insulation, John B. Whitehead, Chairman.

Committee on Fatigue Phenomena of Metals, H. F. Moore, Chairman.

Committee on Hardness Testing of Materials, A. E. Bellis, Chairman.

Committee on Heat Treatment of Carbon Steel, F. B. Foley, Acting Chairman.

Committee on Marine Piling Investigations, R. T. Betts, Chairman, William G. Atwood, M. Am. Soc. C. E., Director. Sub-committees on Biology, Chemistry, Concrete, Finance, Engineering Patents, and Publicity.

Committee on Moulding Sand, R. A. Bull, Chairman, Sub-committees on Geological Surveys, Conservation and Reclamation, Standard Methods for Testing Moulding Sands.

Committee on Neumann Bands, Charles E. Munroe, Chairman.

Committee on Physical Changes in Iron and Steel Below the Thermal Critical Range, Zay Jeffries, Chairman.

Pulverizing Committee, Galen H. Clevenger, Chairman.

Committee on Uses of Tellurium and Selenium, Victor Lehner, Chairman.

Committee on Heat Transmission (in process of organization), H. C. Dickinson, Chairman of Organizing Committee.

Committee on Relation of Quality and Quantity of Illumination to Efficiency in the Industries. (Under consideration.)

These committees have from 6 to 49 members. The direct and indirect expenditures for projects in which the Division has some responsibility are estimated to exceed $2 000 000, but cannot be stated exactly, because many elements cannot be evaluated and accounts cannot be centralized for others, so as to be summarized, without expense and annoyance not justified by the result to be attained.

Except the committees in process of organization, all those named and several others which completed their projects some time ago and have been discharged, have achieved valuable results. For example, much has been added to the knowledge of the behavior of metals under repeated stresses; highway research has been co-ordinated, developed, and stimulated; more is being learned about marine boring animals which destroy wooden piles and means for combatting them; the art of welding by gas and electric current has been notably advanced; and economies in the use of moulding sand are

being effected. Some of these projects are being expanded in response to requests for further information. This is particularly true of the Fatigue of Metals Research to which Engineering Foundation contributed $30 000—its largest single appropriation—and to which the General Electric Company has contributed an equal amount and is adding to this investment. The Allis-Chalmers Manufacturing Company and other industrial corporations, also, are contributing.

Besides aiding in the support of the Division of Engineering and its projects, Engineering Foundation has had other activities. During the World War, it participated in experiments for spray camouflage of ships; a committee reported on the advisability of a laboratory for testing of large water-wheels and other hydraulic equipment of large size; and hollow-crested weirs were investigated under the immediate direction of Clemens Herschel, Past-President and Hon. M. Am. Soc. C. E. A study of the theory, design, and construction of arch dams has been recently undertaken as well as a study of wood-finishing processes in co-operation with the wood-working industries and users of paint and varnish on wood for buildings, vehicles, cars, furniture, and farm implements. An experimental study of reinforced concrete multiple arches is under consideration in co-operation with the Committee on Research of the American Society of Civil Engineers. Recently, Engineering Foundation was suggested as the best independent technical organization to take charge of the technical features of a concerted effort to overcome the cotton boll weevil in the Southern States. This project is under advisement on the understanding that ample funds will be provided by the American Cotton Association with which the proposal originated.

In addition to printing its annual reports for the past three years, Engineering Foundation has published a Progress Report on the Research in Fatigue of Metals, a Directory of Hydraulic Laboratories of the United States, and, since January, 1921, semi-monthly Research Narratives, 5-min. stories of interesting researches in many fields. Engineering Foundation has under consideration, as another project, a proposal for a continuing compilation of original engineering data taken from publications of the societies and technical journals, or contributed by individual engineers. For brevity, this project is known as the "engineering encyclopedia". As a result of activities of Engineering Foundation and the Division of Engineering, numerous valuable papers and articles have been contributed to the societies and technical journals, and the research activities of the engineering societies have been stimulated.

The present income of Engineering Foundation seems small, as compared with the hundreds of thousands, and even millions, of dollars, spent annually for research by some of the most enterprising, and, consequently, prosperous, industrial corporations. The relatively large results mentioned in the foregoing paragraphs have been achieved through co-operation, supplemented by the funds and efforts of the Foundation. As its resources increase, its services can be broadened to an approximation of the expectations of its many friends.

The plans of Engineering Foundation may be simply stated, as follows:

1.—To stimulate the spirit of research among engineers.

2.—To organize, further, or conduct researches or investigations which will benefit the Engineering Profession and the related industries.

3.—To aid in making results of research available to engineers, by contributions to publications of the societies and through other channels.

4.—To strengthen co-operation in research among engineers in various branches of the Profession, between engineers and other technologists, and between engineers and scientists. (There are few, if any, researches connected with engineering or industry which do not involve such co-operation.)

5.—To serve as a clearing house of its member societies for research activities.

6.—To undertake especially such researches as cannot or will not be done by industries, Government, educational institutions, or separate societies, but to co-operate with all these agencies on proper occasions.

7.—To render service to individual engineers and to committees of the societies in all feasible and proper ways.

8.—To perform such broader services to mankind as fall distinctly to its lot, for which means are provided.

The greatest present needs of Engineering Foundation are:

1.—Substantial increase of endowment.

2.—More intimate co-operation of its Founder Societies.

3.—Such adjustment of relations with the National Research Council as will leave the engineering part of the research field clear for Engineering Foundation.

4.—Provision for the participation of the other societies which are now members of the Division of Engineering.

The Founder Societies, having created Engineering Foundation with Mr. Swasey's inspiration and financial aid, seem straightway to have forgotten it, and have continued their research activities separately as if the Foundation did not exist. Here, however, is an instrumentality of great possibilities, belonging to the Societies, which they should develop and utilize to their own advantage and credit, and "for the advancement of the Profession of Engineering and the good of mankind."

A liberally endowed Engineering Foundation, heartily supported by the great Engineering Societies, can seek the solution of many problems in engineering, or of mixed scientific and technical interest that have practical application immediately in view. There is no other foundation in this field; each of the well-known foundations is devoting its resources to other subjects. There is a great opportunity for service.

THE STUDY OF STEELS FOR ENGINEERING STRUCTURES

By George K. Burgess,* Esq.

1.—Introduction

Perhaps it is somewhat unusual for a metallurgist to present a paper before this Society, nevertheless, the subject of structural steel is one that cannot be treated adequately alone by either the civil engineer or the metallurgist. It requires the co-operation of both in best defining the material to be used for the several components of a given structural project, bridge, building, or ship, together with an understanding of relative manufacturing facilities and costs for the several possible materials, and the most economical solution, with sufficient provision for safety and permanence for the purchaser or the user.

The formulation of generally acceptable specifications naturally lags considerably behind the progress of the pioneers in the development of improved materials or methods of application, and the pioneer usually has first to take the risk himself in putting into practice those ideas the advantages of which he is convinced. The history of the development of steels for engineering structures is no exception to this rule.

Properly speaking, and looking forward as well as backward, this development of structural metals may be grouped into four periods, each designated by a class or grade of material: Wrought iron; low-carbon steel (at first Bessemer and then basic open hearth); alloy steels; and heat-treated steels, including high carbon and alloy steels.

The wrought-iron stage gave way to that of Bessemer steel but gradually and, it might be said, with some misgivings; the gradation from Bessemer into basic open hearth met no opposition, it was mainly a question of cost, convenience, and capacity of manufacturing, and Bessemer steel is still furnished for buildings. We are living in an epoch intermediate between the low-carbon steel and the alloy-steel periods. The great mass of structural steel tonnage is low-carbon, basic open-hearth steel, and many think it should remain so; nevertheless, not a few important bridges have been built in which alloy steels have been used, particularly of nickel and more recently of silicon and nickel-chromium, either in combination with carbon steels or alone; and, in a few instances, less important and smaller members of large bridges have been of weight-reducing heat-treated steels.

In addition to the type of steel to be chosen for the various parts of a structure, there are many auxiliary questions that must be considered and to some of which satisfactory answers are not as yet forthcoming, such as the relative behavior of thick and thin sections, of solid and fabricated members, and the best design for each; the limitations of riveting and the possibilities of welding; the allowable working stresses for each class of material, design,

* Chf., Div. of Metallurgy, U. S. Bureau of Standards, Washington, D. C.

and load; the prevention of or protection against corrosion which is a different problem for structures exposed to atmosphere and for enclosed structures as city buildings, parts of which may also be subject to deterioration from stray electric currents; and, as a final illustration, the resistance to and protection from fire.

There is an important reason why the structural engineer should go slowly in accepting new ideas and applying them. Many engineering structures are costly and they are usually built on a non-competitive basis as regards the engineering. The engineer, therefore, holds himself bound to follow accepted practice. For many types of structure, also, he is restrained by building codes and specifications of technical groups or societies that tend to crystallize existing practice.

In contrast to this enforced conservatism of the structural engineer, the freer position of the mechanical engineer, who also deals in metals, should be noted. Employed by the manufacturer, he is engaged in designing and distributing his product under keen competitive conditions and he is thereby stimulated constantly to improve it. The marvelous strides made in the knowledge and economical use of steels by the automotive industry which is now directing attention most effectively to aluminum and its alloys need only to be mentioned to illustrate what progress is possible. The speaker wonders if any bridge engineer has ever considered whether he could advantageously use such an alloy as duralumin for any of the parts of a bridge? As compiled by Mr. H. C. Kneer,* Table 1 gives a comparison of the properties of duralumin and aluminum with those of mild and alloy steels.

TABLE 1.—COMPARISON OF PROPERTIES OF DURALUMIN AND ALUMINUM WITH STEEL.

	Duralumin tempered.	Aluminum half hard.	Mild steel.	Alloy steel.
Specific gravity	2.85	2.7	7.8	7.8
Weight, in pounds, per cubic inch	0.010	0.094	0.27	0.27
Weight, in pounds of 1 sq. ft., 0.1 in. thick	1.44	1.35	3.90	3.90
Tensile strength, in pounds per square inch	55 000	18 000	55 000	125 000
Yield point, in pounds per square inch	25 000*	.....	36 000	100 000
Percentage of elongation in 2 in.	17	7	20	15
Modulus of elasticity, in millions of pounds per square inch	9.4-10	9.8	30	30
Ratio of strength to weight, $\frac{S}{W}$	19 250	6 650	7 050	16 000
Factor, $\frac{S}{W}$, compared, duralumin = 100%	100	33.5	36.6	83
Sectional area for equal weight	1.00	1.05	0.36	0.36

* Values as high as 46 000 lb. per sq. in. have been obtained for yield point, with 15% elongation in 2 in.

The cost of duralumin construction will be found to compare favorably with heat-treated alloy steel, with an increase in strength efficiency of about 17% over alloy steel and 200% over mild steel. Is it possible that we may expect a fifth epoch in structural metals, that of aluminum alloys?

* "Duralumin—A Digest of Information," *Transactions*, Am. Soc. for Steel Treating Vol. 3, pp. 13–42 (1922).

It may be of interest to note that the United States Bureau of Standards is testing about 143 duralumin girders for the new U. S. Navy dirigible, *Z-R1*. These tests have not only given added confidence in the adequacy of these girders, but they have shown that there may be possibilities of lighter construction in future design.

For structural uses of duralumin, there are many factors other than lightness to be considered, such as its low modulus of elasticity—one-third that of steel—which will augment deflections under load; greater rigidity in tubes and channels; the elimination of the need of painting; lower transportation and erection costs; and the possibilty of greater permanence. There is a promising, immediate future for structural items and accessories on transportation units, but for important permanent structures the use of the light aluminum alloys to replace steels is still in the conjectural stage.*

2.—Structural Steel Specifications

As there will be occasion to refer to specifications frequently, it may not be out of place to record some of the specifications in current use for structural steels. In Table 2 are included typical specifications of the American Society for Testing Materials, some of the British Standards Committee, and there are also included a few steels which do not appear to have been endorsed by any specification-making body, but, nevertheless, have been used in important engineering structures. Among these, are a so-called silicon steel and a nickel-chromium steel made from Mayari ores.

It will be noted that the British specifications permit somewhat higher tensile strength, have no elastic limit requirement, and the ductility and chemical requirements are less severe than those of the American specifications.

As to the limitation of sulphur and phosphorus, attention might be called to the fact that it would appear to have been the general practice to frame specification limits for these two elements to meet what could readily be obtained by the current manufacturing practices for structural steel. Thus, the 1901 Specifications of the American Society for Testing Materials for buildings have no sulphur limit and permit phosphorus to 0.1%, and for bridges and ships, the sulphur limit is 0.06% and that for phosphorus 0.08% for acid steel and 0.06% for basic steel; whereas the 1921 Specifications restrict the phosphorus in open-hearth steel to 0.06% for buildings, and for bridges the sulphur limit is 0.05% and the phosphorus limits have become 0.06 and 0.04 per cent. The present physical requirements, on the other hand, are somewhat less severe than those of 1901 for steel for buildings and bridges. The requirements abroad as to sulphur and phosphorus are less severe than the American requirements for structural steel. Thus, the Unified French specifications of 1920 establish by definition† a maximum of 0.1% each for sulphur and phosphorus; the British specifications for bridges contain a maximum for each of these elements of 0.06%, and for general building construction 0.08% for

* See, also, "Some Points of Contact between Metallurgy and Engineering," by O. W. Ellis, *The Engineering Journal*, December, 1922, p. 576.

† Fascicule A1-2.

TABLE 2.—SOME STRUCTURAL STEEL SPECIFICATIONS.

Type.	No.	Process of manufacture.	Phosphorus, Maximum. Acid.	Phosphorus, Maximum. Basic.	Sulphur, maximum.	Carbon, maximum.	Nickel, minimum.	Tensile strength, in pounds per square inch.	Yield point, minimum, in pounds per square inch.	Percentage elongation in 8 in., minimum.	Diameter on 180° cold bend, ¾ in.
A. S. T. M., bridges....	A 7-21	Open hearth	0.06	0.04	0.05	....	....	55 000- 65 000	0.5 Tensile strength	*27.3-18	1 T 2 T 3 T
A. S. T. M., nickel......	A 8-21	Open hearth	0.05	0.04	0.05	0.45	3.25	85 000-100 000	50 000	*17.6-14 R.A.=25	1 T 2 T ...
A. S. T. M., buildings..	A 9-21	Open hearth Bessemer	0.06 0.10	0.06	....	....	....	55 000- 65 000	0.5 Tensile strength	†25.4-18	0 T 1 T 2 T
A. S. T. M., locomotives	A 10-21	Open hearth	0.05	0.05	0.06	....	....	55 000- 65 000	0.5 " "	*25.4-18	0 T 1 T 2 T
A. S. T. M., cars........	A 11-21	Open hearth	0.06	0.04	0.06	....	....	50 000- 65 000	0.5 " "	*30 -18	0 T 1 T 2 T
A. S. T. M., ships.......	A 12-21	Open hearth	0.06	0.04	0.06	....	....	58 000- 68 000	0.5 " "	*26 -18	1 T 1⅛ T 2 T
Silicon	....	Open hearth	0.06	0.04	0.05	0.40 Si. Mn.	0.20-0.45 < 1.00	80 000- 95 000	45 000	‡20 -16.8	1 T 1⅛ T ...
Mayari.................	....	Open hearth	0.06	0.04	0.05	0.40 Ni. Si. Mn.	> 1.20 < 0.15 < 0.30	85 000-100 000	50 000	‡18.8-16 R.A.=30	....
British: Bridges	15-1912	Open hearth	....	0.06	0.06	....	....	62 720- 73 920	....	20 -16§	1½ T
Buildings	15-1912	Open hearth	....	0.08	0.06	....	....	62 720- 73 920	....	20- 16§	1⅛ T
Ships.................	13-1910	Open hearth	....	....	....	....	....	62 720- 71 680	....	20- 16§	1⅛ T

*Based on $\frac{1\ 500\ 000}{\text{Tensile strength}}$.

†Based on $\frac{1\ 400\ 000}{\text{Tensile strength}}$.

‡Based on $\frac{1\ 600\ 000}{\text{Tensile strength}}$.

§For steel below 0.375 in. in thickness.

phosphorus and 0.06% for sulphur, whereas for structural steel for ships there appears to be no chemical limitations.*

Attention may be called to the work of the Joint Committee on the Investigation of Phosphorus and Sulphur in Steel composed of representatives of eleven organizations operating on the unanimous consent basis. This Committee has presented a Preliminary Report on the Effect of Sulphur on Rivet Steel† and this will be followed by others on the various grades of steel. It is expected that the results established by the investigations of this Committee will serve as a basis for the intelligent revision of the sulphur and phosphorus limits. The definite reports are to appear as *Technologic Papers* of the Bureau of Standards. An examination of the results obtained by the Committee, using material from fourteen 75-ton heats, on the properties of rivet steel (carbon = 0.11, manganese = 0.40 to 0.50, and phosphorus = 0.01), with sulphur in steps from 0.03 to 0.18%, shows that residual sulphur within this range appears to affect most of the physical properties only slightly, if at all. In general, the speaker thinks it will be found that high sulphur is of more concern to the manufacturer than to the user of steel.

3.—Modifications of Structural Steels

It has long been considered a desideratum to find an alloying element which can be added to structural steel at low cost and increase its strength and elastic limit without lowering the ductility and without resorting to special thermal or mechanical treatment. It has also been considered by some engineers that the present type of structural steel might be improved considerably by refinements in manufacture without essential change of composition or appreciable increase in cost, thus making for greater uniformity of product which might allow raising the permissible stresses. For certain structural members, also, the possibility of raising the carbon content somewhat at the expense of ductility has been considered, which would make for reduction in weight; and, finally, two or more of these suggestions have been combined, that is, raising the carbon and also adding an alloying element, such as nickel which tends to maintain the ductility, giving a satisfactory structural steel of considerably enhanced permissible stresses, say, 28 000 lb. per sq. in. as compared with 16 000 lb. per sq. in.

A well known factor that must be taken into account in structural steel when weight is decreased and stresses are increased, particularly for structures such as the larger bridges subject to heavy and variable live loads, is the greater deflection and consequent decreased stiffness undergone by the structure. These effects necessarily accompany the use of higher allowable stresses for a material like steel all the alloys of which show no change in the modulus of elasticity. In some cases, this may be counteracted by introducing strains of opposite sign during fabrication; and for each type and design of structure there is undoubtedly a best practice to be followed for a given material. The speaker will not discuss this phase of the question, but will confine himself to some of the metallurgical aspects.

* British Standard Specifications as of November, 1919.

† *Proceedings*, Am. Soc. for Testing Materials, Vol. 22, p. 94 (1922).

There are certain manufacturing characteristics generally common to all steels, but in diverse degree, such as piping, segregation, effect of impurities, including oxides and gas inclusions, internal stresses, and surface defects, but from which ordinary low-carbon structural steel may be and often is singularly free. With the increase of carbon, and especially with alloying elements in increasing quantities, it is more and more difficult and often practically impossible to make steel ingots free from pipe, and these more complex steels are also usually more subject to other defects, such as internal irregularities of composition and surface flaws, all of which results thereby in greater manufacturing losses, such as increased discard for pipe and rejection for variation in composition, properties, or condition of surface. In other words, the difficulties and cost of manufacture increase, as the complexity of the steel increases with, in general, a corresponding uncertainty in uniformity of the product, necessitating also a more rigid inspection.

Keeping these facts in mind, the modifications of structural steel by alloying and deoxidation, as well as the rôle of impurities, may be considered.

Among the alloying or addition elements besides carbon, that have been suggested, and used in some cases, are nickel, alone or together with chromium as for steel made from Mayari ores, vanadium, chrome-vanadium, silicon especially in association with higher manganese, aluminum which appears not to have been used except as a deoxidizer, and titanium. Other possibilities are copper and perhaps molybdenum.

It is interesting to note that as early as 1904, the Pennsylvania Steel Company offered a special high-carbon steel for the structural work of the Manhattan Bridge, in New York City, to have an elastic limit of 45 000 lb. per sq. in., a tensile strength of 85 000 to 95 000 lb. per sq. in., and a percentage elongation in 8 in. of $\frac{1\ 500\ 000}{\text{tensile strength}}$; this steel had from 0.50 to 0.60% of manganese, and 0.45% of carbon, together with low silicon. The question naturally arises, may not a carbon steel of higher yield point than those enumerated in Table 2 be advantageously and safely used for structural purposes?

The properties of the steel mentioned may be compared with the latest specifications, those of the proposed Sydney Harbor River Bridge which has a central span of 1 600 ft. The specifications allow the contractor to use either carbon steel, nickel steel, or chrome-nickel steel. The specifications for plates and shapes up to and including 1 in. in thickness are as given in Table 3.

Considering first the use of nickel in structural steels, the properties of 3.5% nickel-steel have been generally recognized for about fifteen years or more, the manufacturing conditions and costs are well established, and there are in existence widely accepted specifications such as the A8-21 of the American Society for Testing Materials (see Table 2). This material also has been advocated several times before this Society, especially by J. A. L. Waddell, M. Am. Soc. C. E. Carbon is allowed up to 0.45% in this steel, which has a yield point (50 000 lb. per sq. in.) nearly double that of low-carbon structural steel, but with slightly less ductility.

TABLE 3.

	Carbon steel.	Nickel steel.	Chrome-nickel steel.
Minimum tensile strength, in pounds per square inch	62 000-70 000	85 000-100 000	85 000-100 000
Minimum yield point, in pounds per square inch	35 000	50 000	50 000
Percentage of elongation in 8 in.	$\frac{1\,500\,000}{\text{Tensile strength}}$	$\frac{1\,600\,000}{\text{Tensile strength}}$	$\frac{1\,600\,000}{\text{Tensile strength}}$
Minimum reduction of area, percentage	44	40	30

This material was first used in bridge construction about 1904 in the Blackwell's Island Bridge designed by Gustav Lindenthal, M. Am. Soc. C. E. Mr. Waddell has advocated insisting on a yield point of 55 000 or even 60 000 lb. per sq. in. for this grade of steel, but it should be borne in mind that if the chemical composition is kept constant, the yield point can be raised only by thermal or mechanical treatment (as by cold working it), a procedure which tends to make for lack of uniformity of properties. This implies a best value for the finishing temperature of rolling any given section of a material. It may be that a yield point of 50 000 lb. per sq. in. is too low for this material, but the specified tensile strength and ductility are probably also low. This material as used in the construction of the St. Louis Bridge,* for annealed specimens averaged an ultimate strength of 99 850 lb. per sq. in., a yield point of 60 250 lb. per sq. in., an elongation of 17.9% in 8 in., and a reduction in area of 53.3%, with a chemical composition as follows:

Carbon	0.38	per cent.
Manganese	0.58	" "
Nickel	3.45	" "
Phosphorus	0.012	" "
Sulphur	0.03	" "

In the Manhattan Bridge, about 8 000 tons of plates and shapes of nickel steel were used, as well as nickel-steel rivets. The requirements were tensile strength, 85 000 to 95 000 lb. per sq. in., yield point, 55 000 lb. per sq. in., and percentage of elongation in 8 in. of $\frac{1\,600\,000}{\text{tensile strength}}$. Nickel steel has also been used in the following bridges: The new Quebec Bridge, the Frott Bridge in Kansas City, Mo., the Jack-knife Bridge in Chicago, Ill., and the Detroit-Superior High Level Bridge, in Cleveland, Ohio.

The element that may best be compared with nickel for addition to structural steel is copper, which has been shown to increase the strength, yield point, and resistance to shock and to atmospheric corrosion, without loss of ductility. Experimenters have disproved the erroneous idea of embrittlement of low and medium carbon steel by copper.† A steel containing 0.38% carbon, 0.57% manganese, and 0.86% copper, will have a yield point near that of

* "Bridge Engineering," by J. A. L. Waddell, p. 91 (1916).

† See paper by Messrs. Hayward and Johnston, *Transactions*, Am. Inst. of Min. and Metallurgical Engrs., Vol. LVIII, p. 722 (1918), and references therein.

3.5% nickel steel, with considerably greater ductility. In the tests of Messrs. Hayward and Johnston, the elongation in 2 in. was 27.3% and the reduction in area 52.7%, as compared with the requirements of nickel steel of 16 and 25%, respectively, in Specification No. A8-21 of Table 2.

Messrs. Clevenger and Ray* have noted the tendency of copper to segregate toward the bottom of small ingots when more than 0.8% is added as metallic copper. The relatively low cost of copper and the ease with which it may be added to structural steel indicate that it should be recommended, at least after trial in some large heats on full-sized structural members. In fact, this appears to be a most promising field of research from the points of view of engineering, metallurgy, and economy, and it would probably be more than worth while to conduct an investigation to determine the best metallurgical practice, manufacturing costs, and most suitable limits for copper, either alone or with other elements, such as nickel and manganese, in structural steel, similar to that reported by Mr. Waddell† for nickel steels. It may be recalled that some American iron ores contain copper which enters and remains in the steel which often contains 0.25% copper to its improvement. It is possible that there might be advantage in using either the copper-nickel ore from which monel metal is made, for example, or some intermediate product, or even monel metal itself (68% nickel, 28% copper, the residual being mainly iron and manganese), in producing an economical copper-nickel structural steel.

The case for vanadium as an alloying element has been attractively stated by Mr. G. L. Norris,‡ although, as Mr. Waddell pointed out, this exhibit was not without ambiguity either from the metallurgical or cost point of view. The advantages of vanadium appear to be greatest in association with chromium for steels to be heat treated.

An interesting possibility is the greater development of nickel-chromium structural steels using such ores as the Mayari as a base. Large steel columns made from this steel containing from 1.12 to 1.58% nickel and 0.37 to 0.66% chromium were tested at the Bureau of Standards for the Metropolis and Memphis Bridges.§ Some of these steels also had a copper content as high as 0.1 per cent. Credit is due to Ralph Modjeski, M. Am. Soc. C. E., for the first use of Mayari steel in bridge construction, namely, for the Memphis Bridge. A large number of smaller railway bridges have since been constructed in which Mayari steel has been used.

Another alloy steel that is coming into use for structures, such as parts of the Delaware Bridge, is the so-called silicon steel (Table 2) which might perhaps as well be named a silicon-manganese steel as the specifications call for a maximum of 0.40% copper, 0.45% silicon, and 1.00% manganese, with a minimum of 0.20% silicon. The raising of the elastic limit by increase of silicon seems to be of English origin. The Sandbergs urged the use of 0.3 to 0.4% silicon in rail steel about 1903. Silicon steel appears to have been first

* "The Influence of Copper upon the Physical Properties of Steel," *Bulletin*, Am. Inst. of Min. Engrs., No. 82, pp. 2437–2475 (1914).

† "Nickel Steel for Bridges," *Transactions*, Am. Soc. C. E., Vol. LXIII (1909), p. 101.

‡ *Transactions*, Am. Soc. C. E., Vol. LXXVIII (1915), p. 72.

§ *Technologic Paper 184*, U. S. Bureau of Standards.

produced in America by the Cambria and Carnegie Steel Companies in the form of plates and shapes for light torpedo-boat destroyers about 1908 or 1910, for which the U. S. Navy Department desired a steel having a tensile strength of 80 000 to 90 000 lb. per sq. in., and a steel having approximately 0.75% silicon, 0.60 to 0.80% manganese, and 0.30 to 0.40% copper, was produced for that purpose. In 1912, the Carnegie Steel Company, the speaker understands, made the first proposal of a silicon steel for bridge construction, for the eye-bars and structural steel of the Memphis Bridge.

Here, again, is a case in which a so-called impurity, silicon, has become a desirable and relatively cheap alloying element, imparting strength and high elastic limit to the steel. The present specification, however, is really a double one, permitting the physical properties desired (Table 2) to be attained by either high silicon or high manganese. The manufacturers naturally will furnish a steel of an adjusted composition, depending on the relative price of ferro-silicon and ferro-manganese. Steel of this kind was also tested at the U. S. Bureau of Standards in the form of large columns for the Metropolis Bridge.* The Bureau is now making additional tests of this steel made into fabricated parts for the Delaware Bridge.

The rôle of titanium has been well described by Mr. N. Petinot† to be primarily that of a deoxidizer and scavenger and an effective agent for reducing segregation. It is usually added with the ladle additions in the form of ferro-carbon-titanium containing 16% titanium, about 8 to 12 lb. of ferro-carbon-titanium per ton of steel (0.06 to 0.08% titanium), and there remains in the steel less than 0.02% titanium.

The U. S. Bureau of Standards is completing an investigation of the manufacture and properties of two 1 000-ton lots of rail steel (0.75% copper and 0.76% manganese) treated with titanium, as compared with similar steel deoxidized with ferro-silicon. The mechanical properties of these two steels are not markedly different, but the titanium-treated steel has less segregation in the upper part of the ingot and shows a slightly greater tendency toward piping. One would expect still less differences for low and medium carbon steels.

With regard to the possibilities of improving the physical properties of ordinary structural steel—yield point and ductility—by endeavoring to produce steel more highly "purified", it is questionable whether much is to be gained by this means. A series of experiments‡ just completed at the Bureau of Standards on the mechanical properties of pure alloys of iron, carbon, and manganese, containing no phosphorus, with less than 0.01% sulphur and silicon for most of the samples, show that, although there is a slight improvement in ductility, there is a corresponding decrease in strength and elastic limit as compared with commercial steels of the same carbon and manganese contents.

In view of the almost negligible importance of the phenomena of fatigue for most structural steels of interest to the civil engineer, the question of freeing the steel still further from entrained inclusions, although it may be

* *Technologic Paper 184*, U. S. Bureau of Standards.

† *Transactions*, Am. Soc. C. E., Vol. LXXVIII (1915), p. 50.

‡ *Technologic Paper 453*, U. S. Bureau of Standards.

said to be desirable, appears not to be vitally essential, and probably would not allow raising the permissible stresses, whereas the cost would be increased. Structural steel is much less subject to abuse in service than rail steel, for example, and the manufacturing practices permitted by the specifications for rail steel do not necessarily result in clean steel. This should not be taken as an argument for dirty steel, but it must always be borne in mind that for any engineering material there is a most economical procedure in manufacture to meet the engineering requirements. The manufacturer, in general, can meet more rigid requirements, but not without increased costs, except as his art is improved.

Evidently there are possible uses of heat-treated steels in engineering structures, and such steels have been introduced to a limited extent in lattices and auxiliary parts. The difficulties of furnishing a reliable and uniform product increase rapidly with the size of heat-treated pieces, as well as the difficulties and costs of joining by rivets or otherwise. For certain structural purposes, as parts of bridges, the line of least resistance would seem to be the development, first, of higher carbon steels which may be air-quenched by some method, such as the Sandberg process. After a study has been made of the most economical alloying element or combination to give maximum yield point without serious loss of ductility in steel to be air-treated, it may be possible to consider liquid quenched and tempered steels, although, in the beginning, these steels should be limited to small parts.

Mr. Modjeski appears to have been the first to have used heat-treated eye-bars for bridges. For the Memphis Bridge, he used Mayari steel for which the rather mild treatment consisted in an anneal at about 1 500° Fahr., followed by an air quench. These heat-treated eye-bars, as specified by Mr. Modjeski, and as furnished by the Pennsylvania Steel Company, had the properties given in Table 4.

TABLE 4.

	Specified.	Furnished.
Minimum tensile strength, in pounds per square inch	80 000	90 000
Minimum elastic limit, in pounds per square inch	47 000	56 000
Minimum elongation, percentage	10	13

This composition was approximately, as follows:

Carbon	0.35	per cent.
Manganese	0.70	" "
Nickel	1.40	" "
Chromium	0.45	" "

It is questionable whether it will be found economical or safe to urge the use of severely heat-treated alloy steels for the main members of engineering structures, and, at present, there are few manufacturing concerns equipped, or with adequate experience, for such production. In parts of structures

subject to fire hazard, the use of heat-treated struts would be an additional hazard as, in general, they lose their enhanced properties with rise of temperature.

4.—Problems in the Use of Steels for Structures

No pretense is made that this list of problems is complete. It is limited to a brief consideration of some of those of which the Bureau of Standards has contributed to the solution. Although of apparently great diversity, they all have to do with the limitations of the use of structural steels.

Fire-Resisting Qualities.—In certain types of engineering structures subject to fire hazard, such as buildings, it is of prime importance to know accurately the behavior of steel at high temperatures. It is also of interest to determine whether it is possible to develop a structural steel which maintains its strength at high temperatures, as well as the safe temperature limits, and also the most effective method of protecting steel columns against fire.

The determination of the mechanical properties of various steels with changes in temperatures up to 650° cent. (1 200° Fahr.) is being conducted at the Bureau of Standards by Mr. H. J. French. The results have been published* on the Effect of Temperature, Deformation and Rate of Loading on the Tensile Properties of Low-Carbon Steel (0.17 to 0.25% carbon, 0.40% manganese) and on the Tensile Properties of Some Structural Alloy Steels at High Temperatures.†

It may be stated in brief that a low-carbon steel has its maximum strength between 250 and 300° cent. (480 to 570° Fahr.) and minimum ductility throughout a somewhat wider range. Above 300° cent. (570° Fahr.), the strength decreases rapidly accompanied by rise in ductility, whereas the elastic limit begins to decrease at a somewhat lower temperature than the strength. At 450° cent. (760° Fahr.), the tensile strength becomes about two-thirds of its value at normal temperature, and the elastic limit from one-half to two-thirds this value. This material moderately cold-worked by rolling maintains the imparted properties of increased elastic limit and slightly diminished ductility to a temperature of 465° cent. (870° Fahr.).

Tests made at various high temperatures on a number of carbon and alloy steels indicate that above about 550° cent. (1 020° Fahr.), the strength of all steels is low and decreases rapidly with increase in temperature. In the higher temperature ranges, the metal is plastic and will continue to deform as long as the load is maintained, and finally will fail.

It is improbable that any steels can be produced to stand continuously or for reasonably short intervals appreciable loads at temperatures above about 650° cent. (1 200° Fahr.), except in cases where large proportions of alloying elements are added to reduce the iron content to such low values that the resulting product cannot correctly be called steel.

However, at temperatures near 450° cent. (760° Fahr.) and less, it is possible to improve the strength of ordinary structural steels by additions of such elements as chromium, cobalt, and uranium, and less effectively with

* *Technologic Paper 219,* U. S. Bureau of Standards.
† *Technologic Paper 205,* U. S. Bureau of Standards.

nickel, or combinations of these and other elements, or by heat treatment, the relative strength at the high temperature of the different combinations being roughly proportional to the properties at room temperature.

There would appear to be no economic advantage, therefore, except possibly in some very special cases, of modifying structural steel to resist high temperatures. This opinion is greatly strengthened by the investigation of Fire Tests of Building Columns,* recently conducted by Mr. S. H. Ingberg and his associates as a joint problem of the Bureau of Standards, the Underwriters Laboratories, and the Associated Factory Mutual Fire Insurance Companies.

The purpose of this investigation was to ascertain (1), the ultimate resistance against fire, of protected and unprotected columns as used in the interior of buildings; and (2), their resistance against impact and sudden cooling from hose streams when in a highly heated condition. The series consists of tests of 106 columns, of which 91 were fire tests and 15 fire and water tests.

The fire-test series include (1), tests of representative types of unprotected structural steel, cast iron, concrete-filled pipe, and timber columns; (2), tests wherein the metal was partly protected by filling the re-entrant parts or interiors of columns with concrete; (3), tests wherein the load-carrying elements of the columns were protected by 2 or 4-in. thicknesses of concrete, hollow clay tile, clay brick, gypsum block, and also a single or double layer of metal-lath and plaster; and (4), reinforced concrete columns with 2-in. integral concrete protection.

The test columns were designed for a working load of approximately 100 000 lb., as calculated according to accepted formulas, the amount varying somewhat for the different sections. The load was maintained constant on the column during the test, the efficiency of the column or its covering being determined by the length of time it withstood the combined load and fire exposure.

The column was exposed to fire by placing it in the chamber of a gas-fired furnace, the temperature rise of which was regulated to conform with a predetermined time-temperature relation. Measurements were taken of the temperature of the furnace and test column and of the deformation of the column due to the load and heat.

In the fire and water tests, the column was loaded and exposed to fire for a pre-determined period, at the end of which the furnace doors were opened and a hose stream applied to the heated column, the duration of the application and the pressure at the nozzle varying with the length of time the corresponding type of column withstood the regular fire tests.

The steel for the seventy-seven steel columns was basic open-hearth, conforming within 10%, above or below, the specifications of the American Society for Testing Materials for structural steel for buildings (Table 2) and the applied working loads averaged 11 600 lb. per sq. in.

The time to failure of the unprotected structural steel columns varied from 11 to 21 min. The difference in results for the various column types, although in part due to variation in furnace exposure, is attributable also to difference in thickness of metal and in the unit loads sustained, sections with thin

* *Technologic Paper 184*, U. S. Bureau of Standards.

members under the higher unit loads failing more quickly than sections the members of which were arranged to form heavy metal thickness.

The average time to failure of the eight structural steel sections was 15 min., and the average period of expansion was 13 min. Maximum temperatures from 578 to 668° cent. (1 072 to 1 234° Fahr.) were attained on the outside of the metal near the edges. It is difficult to estimate the average effective temperature, as the rise was too rapid to permit assuming temperature uniformity over the thickness of the metal. Tests recently made at the Bureau of Standards on small specimens* indicate that, for the loads sustained by the unprotected columns, the failure temperatures of the structural steel fell within the limits of 550 to 650° cent. (1 022 to 1 202° Fahr.). The failure in the fire test in all cases was due to decrease in mechanical strength of steel with increase in temperature.

Apparently, it appears hardly profitable to secure a little greater fire resistance of structural steel by alloying or treatment, as heat-insulating protection would still be necessary, unless greater fire resistance could be attained incidentally with greater general strength and uniformity. If, however, the working unit stresses are increased in proportion to the resulting increase in elastic limit or ultimate strength, the gain for fire resistance would probably be small, as it decreases with increase of load imposed.

In contrast to the quick response of only a few minutes of unprotected steel to fire conditions, it may be noted that for the reinforced concrete columns tested, the time to failure averaged more than 8 hours.

Expansion.—A knowledge of change in length with rise in temperature is of considerable importance in the design of certain structures. The Bureau of Standards is equipped for determining the thermal expansion at high and low temperatures, and the expansion coefficients have been measured† by Messrs. Souder and Hidnert for a number of steels, a few of which are indicated in Table 5, from which it is seen that, except for very unusual compositions, the expansion coefficients of most steels do not differ greatly.

Painting Structural Steel.—The question of the protection of Structural steel by paint has received considerable attention at the Bureau of Standards, and specifications have been published, some of which are among the first to be promulgated as United States Government specifications by the recently organized Federal Specifications Board.

After thorough mechanical cleaning to remove rust and scale, the Bureau recommends protecting structural steel with at least two and preferably three coats of red lead, linseed oil paint. This red lead paint should be mixed on the job and used within 24 hours after mixing. Directions for mixing red lead for three-coat work on steel, tinted so as to give a final dark brown color, are given on page 79 of *Circular 69,* Paint and Varnish. Specifications for red lead are given in *Circular 90,* for linseed oil, in *Circular 82,* for turpentine, in *Circular 86,* and for drier, in *Circular 105.*

For additional color coat, paints meeting the specification of *Circular 94,* United States Government specification for Black Paint, Semi-paste and

* *Technologic Paper 205,* U. S. Bureau of Standards.

† *Scientific Paper 433,* U. S. Bureau of Standards.

Ready Mixed, *Circular 93,* United States Government specification for Iron-Oxide and Iron-Hydroxide Paints, *Circular 89,* United States Government specification for White Paint and Tinted Paints Made on a White Base, Semi-paste and Ready Mixed, and *Circular 97,* United States Government specification for Green Paint, Semi-paste and Ready Mixed, may be used. Expense may be saved with no very great decrease in the quality of the job by using one of these paints in place of the third red lead coat, but other paint should not be substituted for the first and second red lead coats.

TABLE 5.—STEELS: AVERAGE COEFFICIENTS OF EXPANSION ON HEATING.*

COMPOSITION.						25 to 100° cent.	25 to 300° cent.	300 to 600° cent.	25 to 600° cent.
Carbon.	Manganese.	Silicon.	Nickel.	Chromium.	Copper.				
0.02	0.00	0.006	Co. Cu. Ni. total 0.014			12.0	13.3	15.9	14.7
0.252	0.06	0.007	....	....	....	11.1	12.5	16.0	14.3
0.41	0.64	0.086	....	....	....	11.1	12.7	15.8	14.3
0.388	1.21	1.04	3.67	....	....	11.6	12.3	15.0	13.7
0.326	0.78	0.094	3.59	....	....	10.9	12.1	15.3	13.8
0.168	0.01	0.135	3.94	2.50	$V = 0.39$	10.8	12.1	14.3	13.3
0.35	1.42	0.20	....	1.00	$V = 0.11$	12.4	13.3	15.6	14.5
0.67	0.77	0.19	....	....	....	11.7	13.0	....	....
0.144	0.10	0.034	$V \pm 0.21$	1.15	1.85	11.2	12.7	15.7	14.3
3.08	(?)	1.68	....	....	....	8.4†	11.6†	Grains	
0.14	(?)	(?)	34.52	....	....	3.7	9.2	18.2	13.6
0.35	(?)	(?)	....	13.0	....	10.0	11.0	13.3	12.2

* The values of the coefficients given in Table 5 should be divided by 10^6.
† Approximate only, as this material increases permanently in length.

Electrolytic Deterioration.—From time to time there have been reports of serious damage to structural steel, particularly reinforcing material in concrete, in the footings of buildings, bridges, elevated railways, and similar structures. A few years ago, this hazard was thought to be serious and in consequence of this fear, Mr. Burton McCollum and his associates at the Bureau of Standards made an exhaustive research of electrolysis in concrete and electrolytic damage to bridges, steel frame buildings, and similar structures. The net result of this investigation was that in very extreme cases some damage might occur from this source, but that the conditions necessary for any serious damage to result were far more extreme than those likely to be found in practice. Many reports of alleged damage to such structures were carefully investigated, and it was found that in all cases such damage was due to causes other than electrolysis, with the single exception of the corrosion of the bases of elevated railway structures where, for obvious reasons, electrolysis conditions were particularly severe. If the most obvious and elementary precautions are taken, such as avoiding metallic connection with power circuits, in the case of the building foundations, and of metallic connection with rails, in the case of elevated railway structures, no trouble from this source is to be anticipated.

Failures.—One of the important functions of the Bureau of Standards, is the study of metal failures. As illustrations in the field of structural metals may be mentioned the examination of the parts of a railroad bridge and of

a roof truss. Such examinations include chemical analysis, tests of mechanical properties, and a detailed metallographic study of the material.

The bridge material, submitted by the Board of Railroad Commissioners of the State of Iowa, was of wrought iron from a diagonal member of a single-system, Warren truss bridge of 85 ft. span, that failed under the load of a locomotive of the Pacific type and a tank car. A study of the failed parts showed inferior material laminated to an excessive degree, with evidences of long continued over-stressings of the material.

The roof truss was taken from the Knickerbocker Theatre after the disaster at Washington, D. C., and submitted by the Building Inspector of the District of Columbia. The material was taken from Trusses 11 and 12, one of which certain of the interested parties had claimed to be of defective material. The tests at the Bureau of Standards showed this material to be well within the specifications for this class of structural steel and to be free from structural features and inclusions which would lead one to regard the steel as defective. Chemical analysis showed carbon, 0.12%, manganese, 0.55%, phosphorus, 0.014%, sulphur, 0.046%, and silicon, 0.03%; the mechanical properties of the several parts ranged as follows: Tensile stress, 51 200 to 56 100 lb. per sq. in.; yield point, 33 200 to 36 300 lb. per sq. in.; elongation in 8 in., 30 to 36%; reduction in area, 58 to 64%; Charpy impact value, 105 ft-lb.; and Izod, 79 ft-lb. Thus, this material apparently failed from an external cause, such as a blow during the collapse of the structure.

Reinforcement Bars.—Considerable attention has recently been given, by specification-making bodies such as the American Society for Testing Materials and the testing laboratory at the Bureau of Standards under the direction of W. A. Slater, M. Am. Soc. C. E., to the question of the determination of the characteristics of concrete reinforcement made from salvaged steel, such as re-rolled rails. Such an investigation is of great practical importance in view of the large available quantity of such material and the fact that its use is quite generally prohibited at present, on account of alleged brittleness, causing breakage in handling, and the uncertainty of its behavior in structures.

The Bureau of Standards has made tests on bars purchased from a number of warehouse stocks. From these tests, it appears that either re-rolled or new billet steel with yield points up to 60 000 lb. per sq. in., which meet the tension and bend tests, would be satisfactory for concrete reinforcement. From these tests, it appears doubtful whether steel having a yield point greater than 60 000 lb. per sq. in. can be bent to meet conditions in practice, but reinforcement not required to be bent should be satisfactory if it meets the tension test and suitable impact or bending tests to detect brittleness. The brittleness appears to be associated more with the yield point of the material than the treatment of the bars in re-rolling them. It is important that this subject be investigated adequately in view of the possibility of salvaging large quantities of old rails by re-rolling for use in reinforcement bars.

This question is closely linked with the subject of deformed bars and allowable bond stresses between concrete and steel. Some types of deformed bars develop weakness on bending, due to more or less sudden changes in area of section. Present practice tends toward elimination of sudden changes in

section for that reason, but the efficiency of a bar in resisting the tendency to slip is involved in this to an important degree. Tentative standards of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete permit a bond stress 20% greater for an "approved" deformed bar than for a plain bar, but the Committee has arrived at no agreement as to the shapes of deformed bars which it approves. It has not even agreed on the form of test specimen which will give the proper comparison between plain and deformed bars.

The divergencies of opinion are sharp on the questions involved in all the reinforcement bar problems and further extensive investigation of the entire problem is imperative.

Permissible Stresses for Steel in Buildings.—If the cost of steel structures is to be lowered, it can be done most effectively by increasing the stress and using the material more efficiently.

The increase from 16 000 to 18 000 lb. per sq. in. for the new Hotel Statler in Buffalo, N. Y., is a move in that direction, which is receiving considerable consideration. If steel is to hold its own in cost with other structural materials, particularly reinforced concrete, the stresses must be increased.

Mr. H. L. Whittemore, of the Bureau of Standards, has made a study of the present status of this subject, based on ordinary structural steel, taking account of conclusions drawn from various tests, on solid and fabricated columns, made at the Bureau and elsewhere, as well as present practice as illustrated in manufacturers' and engineering handbooks and as formulated in about sixty-three municipal and other building codes, including also some foreign specifications and those proposed by various American committees and prominent structural engineers. It is expected that this survey will be published soon in full.

In that study, emphasis is laid on the necessity for inspecting and testing structural steel if more than one quality is commonly used. This and the obtaining of higher strength would increase the cost of the steel somewhat. The same results might be obtained by designing structures for the actual maximum loads they would carry. Thus, a lightly loaded residence would require periodic inspections to prevent its being overloaded if a change in the surroundings made it desirable to use it for manufacturing purposes.

If the load is constant and its value known, it is probable that stresses near the yield point could occur before failure. The greater factor of safety required by most city building codes is made necessary by the uncertainties of the properties in the material and the load which will actually occur. Nearly all codes for American cities limit the stresses to 16 000 lb. per sq. in. The maximum stresses in long columns $\left(\frac{l}{r} = 90\right)$, as given by any formula or any building code (Buffalo, N. Y.), is 11 970 lb. per sq. in. There has been no tendency to increase this limit in recent years, but rather to decrease it for large ratios of $\frac{l}{r}$.

Even German specifications, otherwise more liberal than American specifications, are very conservative on this point. Considering the damage which

may result from the failure of a column and the uncertainties in regard to actual loading, workmanship, and uniformity of the material, it is believed by Mr. Whittemore that the values given by the formula proposed by the Special Committee on Steel Columns and Struts,* namely $S = 20\,000 - 100 \frac{l}{r}$, should not be exceeded. Possibly higher stresses than the limiting value of 12 000 lb. per sq. in., given by the Committee, might be used for short columns $\left(\frac{l}{r} = 40, \text{etc.}\right)$.

In considering this matter, it should also be borne in mind that it appears to be the opinion of some of the most eminent American engineers that it is safe to raise the permissible stresses for steel in buildings from 16 000 to 18 000 lb. per sq. in., if precautions are taken to check the grade of steel and inspect thoroughly its erection, with limitations on the increase of the live load. This subject, of such great complexity and economic importance, is now in the hands of the Special Committee on Stresses in Structural Steel of the Society. The speaker ventures the suggestion, which, perhaps, has already been considered, that procedure under the rules of the American Engineering Standards Committee, with the Society as sponsor, would be a most efficacious method of securing co-operation of all interested bodies and of establishing a standard American practice for each class of structure and material.

Riveting and Welding of Structures.—The scope of this paper will permit only a passing reference to these important subjects. Attention might again be called to the report of the Joint Committee on the Effect of Sulphur on Rivet Steel (Section 2). Mention has also been made of the early use of nickel-steel rivets in bridge construction (Section 3), which permits the use of rivets of smaller section. In spite of the apparent economy and advantages to be secured, their use does not seem to have increased to the extent that might have been expected. There are undoubtedly outstanding factors yet to be considered; thus, the nickel-steel rivet is somewhat harder at the temperature at which it is driven and may fail to fill the hole as thoroughly as a carbon-steel rivet. It is also more difficult to cut out cold nickel-steel rivets owing to their greater hardness and toughness. It would seem that these difficulties were not hard to overcome; thus, use of the newer electric rivet-heating furnace would enable the operator to produce a higher temperature and, consequently, the softness necessary to drive the rivet satisfactorily, and the burning-off method could readily be used to remove cold rivets.

An important problem in engineering design planned to be conducted at the Bureau of Standards for the U. S. Navy Department concerns the strength of riveted connections, and is of especial interest not only for the completeness of the contemplated test schedule and methods of test, but also because the riveted joints to be tested are the largest specimens thus far suggested. The test specimens will be 22 in. wide, and 13 ft. long, will contain as many as twenty 1-in. rivets on each side of the plate joint, and with supplementary

* *Transactions*, Am. Soc. C. E., Vol. LXXXIII (1919–20), p. 1583.

pulling grips will take up the full length of the large Emery testing machine, as well as require its full capacity to produce joint failure.

Thorough and precise exploration of stress distribution, of frictional failure and joint strength are contemplated, and it is further hoped to secure valuable data on the following points:

(*a*) The effect of plate material on rivets. (Three grades of steel plates, mild steel, high strength steel, and special treatment steel, the latter possibly a nickel alloy steel and two grades of rivet steel are now proposed).

(*b*) Effect of rivet size ($\frac{7}{8}$-in. and 1-in. rivets).

(*c*) Effect of the increase in the number of rows of rivets on joint strength and the distribution of the load between the rows of rivets.

(*d*) Effect of the omission of alternate rivets in the outer row.

(*e*) Study of the strength of a special form of joint.

(*f*) Study of the strength of joints in two-course plating.

The joints will be tested in triplicate and the present contemplated program calls for sixty-six specimens.

Rapid progress is being made in the welding of steel structures, about twenty or thirty structures of note having been constructed, some of which are very large. According to F. P. McKibben, M. Am. Soc. C. E., most of them have not been very carefully designed with welding in view. Many, in fact, were designed as riveted structures, but were changed by shopmen to be electrically welded. The development of stresses due to welding is not comparable with the stress conditions of riveting, and suitable allowance should be made in design and erection to provide for these differences. There is also need for much more experimental work in the testing of welded joints. Professor McKibben states that his examination of welded steel structures shows that the tension tests, as ordinarily made on butt welded specimens, are not of much value in giving adequate data to designers. Tests appear to be needed on the shearing strength of welded joints.* The art of welding is still in its infancy and a great deal is yet to be done in the improvement of the technique of the various methods, and the choice of welding rods to produce welds in which the added metal is of satisfactory quality. The Bureau of Standards has done some work along these lines, particularly with reference to studies of gas-welding equipment† and the study of gas content of welds as affecting physical properties,‡ and the American Bureau of Welding is actively conducting an extensive research program covering many problems in the development and use of welding.

A problem relating to structures in the comparison of welding and riveting is being studied at the Bureau with the American Bridge Company which has been experimenting with a new process of resistance electric welding, making use of pressed or inserted buttons to localize the welding action. About 150 comparative tensile tests of plain plate-riveted and welded joints were made. The welded joints were from 2 to 23% stronger than the riveted joints, the

* See article by A. S. Humphreys, Jr., in *Iron Age,* May 25, 1922.

† *Technologic Paper 200,* U. S. Bureau of Standards.

‡ *Technologic Paper 179,* U. S. Bureau of Standards.

average being about 15 per cent. In no case did the welded joint show a lower strength than the corresponding riveted joint.

In addition, comparative tests were made on three riveted and three welded girders in cross-bending, and three riveted and three welded columns, with slenderness ratio of 120, with flat ends, under axial load. None of these girders failed due to either rivet or weld failure. The welded girders averaged 1% stronger than the riveted girders and the welded columns average 13% weaker than the corresponding riveted columns. Supplementary coupon tests showed that this difference could not be ascribed to differences in the material. In all cases the welded girders deflected more under load than the corresponding riveted specimens, the average being 6 per cent. It is highly probable that the differences in column strength are due to this greater flexibility which could be overcome by more closely spaced or larger welds.

The general conclusion is, that in structural members, welding shows sufficient promise of becoming an economical substitute for riveting, to warrant the extensive series of tests which would be necessary to establish the limitations of its usefulness.

5.—Experimental Studies of Structural Parts

In the structural engineering field there are many unsolved problems concerning the distribution of stress in, and the strength of, various structural members and their connections. Many of the rules governing designs are based on the results of theoretical analysis, or exchange of thought by discussion, or are the summation of constructional experience. Some of these rules are obviously empirical, others have been founded on relatively meager experimental data, and many of them lack experimental proof. Engineers do not always know, therefore, whether they are just within the safe limit in their practice or whether they are far too conservative. As the magnitude and importance of structures have increased, the rules, at times, have proved inadequate. At other times, some of the limitations accepted are the relative economy of various designs to the fire. Decisions of the latter type need to be verified by data in order to allow correct appraisal.

The equipment available for investigations in this field at the Bureau of Standards consists of an Olsen vertical machine of 10 000 000 lb. capacity, in which columns up to 24 ft. in length can be tested in compression; an Emery horizontal machine with a load capacity of 2 300 000 lb. in compression and 1 150 000 lb. in tension for lengths up to 33 ft.; and several smaller machines. These machines are now in laboratories at Washington. To meet the demand for tests at higher loads, the Bureau would like to be able to acquire a machine of the Emery type with a capacity of 20 000 000 lb., and tentative plans for such a machine have been prepared.

Tests of Columns.—One of the most important investigations on columns conducted at the Bureau of Standards was made under the jurisdiction of the Special Committee on Steel Columns and Struts of the Society.* This investigation, which consisted of a series of tests of 180 columns of various sizes, design, and material, has been very thoroughly discussed, although it is

* *Transactions*, Am. Soc. C. E., Vol. LXXXIII (1919–20), p. 1583.

possible that the data available from these tests have not been utilized to their fullest extent. The program was much more elaborate than was actually completed, and in its Final Report the Committee expressed disappointment at the reception of the report by the Profession.

It might be wise to extend the work of this Committee, and in that connection the speaker wishes to suggest that if such a Committee on Column Tests is again organized that it include, as in the Joint Committee for the Investigation of Sulphur and Phosphorus in Steel (see Section 2), representatives from all interested groups, such as structural engineers, steel and structural manufacturers and consumers, independent metallurgists, best accredited through technical organizations, and the Government laboratories, by which procedure it seems certain that the various aspects of the problem will receive due consideration. It is not a reflection on a committee of civil engineers to state that some of the metallurgical and manufacturing aspects of their problem were not adequately considered in planning these column tests.

Another series of tests on forty-two columns was made for the American Railway Engineering Association, the results of which have been published by that Association.*

A third series was made of eighteen large bridge columns described by J. H. Griffith, M. Am. Soc. C. E., and Mr. J. G. Bragg,† including items for the St. Louis Municipal Bridge, the Chicago, Burlington and Quincy Bridge, at Metropolis, Ill., and the Memphis Bridge. It is perhaps worthy of remark that some of these tests were the first and only tests that have been made of alloy steel columns of large size. These alloy steels included nickel, Mayari, and silicon steels.

At the request of the American Bridge Company a comparison was undertaken of solid columns of various thicknesses with corresponding fabricated columns, a total of thirty-nine columns. This is being supplemented with tests now in progress on material furnished by the Bethlehem Steel Company. The latter program comprises seventy-two columns, submitted with the object of rounding out more conclusively the comparison of the behavior of the solid and fabricated column types. Several auxiliary matters are also being considered, such as the effect of variation in size and location of test coupons, comparison of thin and thick sections, and the effect of change in yield point of material on test results of columns. It is hoped to be able to complete and publish this series of tests soon.

Structural Steel Angles.—The Bureau of Standards has recently published,‡ from material furnished by the American Bridge Company, a series of compression tests on 170 standard rolled structural steel angles, of various design, made from low-carbon steel. The specimen which sustained the greatest unit load for a given slenderness ratio and method of fastening, in most cases suffered the least lateral deflection, and the angle which bent most, sustained the lowest unit load at failure, the deflection being measured at four-ninths of the theoretical maximum load.

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* *Bulletin 21* (No. 223), pp. 474–501, January, 1920.

† *Technologic Paper 184*, U. S. Bureau of Standards.

‡ *Technologic Paper 218*, U. S. Bureau of Standards.

For large slenderness ratios, the average values are well represented by Euler's formula for long columns, calculated for different values of the end fixation factor.

The Karman curves, re-calculated for a yield point of 37 000 lb. per sq. in. and a modulus of elasticity of 30 000 000 lb. per sq. in., represent the average results for small slenderness ratios for several methods of end fixation, except for $\frac{l}{r} = 80$ to 85, where the effect of eccentricity was greatest.

For angles with ends folded, the column formulas considered do not represent the results found in this series of tests.

Short Column Sections.—In the cellular construction of the towers of the Delaware River Suspension Bridge, the speaker understands that there were questions relating to the best distribution of metal in the several parts of the I-sections to be used, that required further experimental study. Accordingly, further I-shaped column sections of silicon steel, 10 ft. in length, of constant depth, and $35\frac{1}{2}$ in., back to back of angles, have been prepared for test purposes by the Bethlehem Steel Company for the Delaware River Bridge Joint Commission, and such tests are now under way at the Bureau.

The flanges of these columns are similar throughout, being 6 by 4-in. by $\frac{3}{4}$-in. angles, the variable element being the web thickness and its concomitant variation of ratio of web thickness to unsupported transverse width. The web thicknesses vary from $\frac{3}{8}$ in. to $1\frac{1}{2}$ in., giving a ratio of thickness to unsupported width of 61 to 15, the total areas of the sections varying from 40 to 80 sq. in. The four heavier sections have webs composed of two $\frac{1}{2}$-in., or two $\frac{3}{4}$-in. plates, stitch riveted. The details of the methods of tests have been briefly summarized in a recent publication.* About one-half the tests have been completed, and it is hoped that the results of this investigation will be available in the near future.

Inferences from Column Tests.—The major column investigations at the Bureau of Standards, in addition to furnishing much valuable information about the individual columns under test, have indicated the possibility of one general conclusion of great importance. Within the slenderness range of ordinary commercial construction, say, from values of $\frac{l}{r}$ between 30 and 90, the major factor in determining the strength of sturdy columns is the physical character of the material of which they are constructed and, in particular, the behavior of this material near the yield point stress. As a striking example of this fact, may be mentioned two columns, of identical construction, tested in the same manner in the same machine. One carried a load of about 3 500 000 lb. and the other only about 2 400 000 lb. Coupons cut from the two columns showed that the yield point of the steel in them was nearly in the same ratio as these loads.

Dr. Tuckerman who is working on this problem at the Bureau of Standards, considers that the general laws of column action therefore can only be worked out when the relationship between column strength and physical

* *Engineering News-Record,* Vol. 89, p. 986, December 7, 1922.

properties of the material have been thoroughly studied. A sufficient theoretical foundation seems to have been laid in the work of Engesser, Considére, Jasinsky, Meyer, Karman, Southwell, and others, but there are very few experimental investigations in which the results of column tests are correlated with thorough coupon tests of the material. The preliminary experimental work in this field must almost of necessity be made on small specimens, as the technical difficulties of producing large columns with a fine gradation of physical properties are great and the cost would be excessive.

The Bureau has in progress an investigation of this kind covering small specimens of materials of widely differing yield points and different moduli of elasticity. The results of this series of tests should help to make clear the way for a better understanding of the general laws of column action.

In addition to this study of general laws of column action, there is a wide field of usefulness in particular tests of particular structures. In this field, because of its equipment of large testing machines, the Bureau of Standards can perform a very useful service. As an illustration of this type of research, the testing of 143 duralumin girders for the new Navy dirigible, *Z-R1,* has already been mentioned. The work at present being conducted for the Delaware River Bridge Joint Commission is another illustration. These tests will enable the engineers to proceed with the construction of the towers with an added feeling of security in the design.

There evidently is much work of this kind of immediate value to structural engineers, which could profitably be done at the Bureau of Standards, and, in the speaker's opinion, the main problems of this nature should be attacked with the co-operation of a representative committee, as outlined previously.

6.—New Testing Devices

The speaker wishes to call attention to two new testing devices recently developed at the Bureau of Standards. These improvements, one of which is a method of visual examination of stresses in metal structures as the yield point is attained and the other an instrument for measuring variations in strains or stresses of materials or structures under load, give promise of great usefulness in engineering.

Method of Mr. R. S. Johnston for Detecting Lüder Lines.—In the early stages of the investigation of the members for the Delaware Bridge, it was apparent that the so-called Lüder lines which appear under certain conditions, after the material has been stressed to the yield point, would offer valuable data on the distribution of stress in the test specimen. A study of this question led to the development of a simple method of making these Lüder lines readily observable, which permits of photographic recording of the development of stress. The method consists in applying a thin wash of Portland cement.

It is believed that this recent development at the Bureau, is the first time visualized stress distribution has been exhibited so clearly on other than laboratory test specimens, and being adaptable to such large test members as are here discussed, seems to offer a new and interesting field in structural engineering research. Mr. Johnston expects to be able soon to publish an account of this investigation.

TABLE 6.—PUBLICATIONS OF THE U. S. BUREAU OF STANDARDS RELATING TO STRUCTURAL STEELS.

Title.	Author.	Class of paper and number.	Number of pages.	Date.
Melting Points of the Iron Group Elements by a New Radiation Method............	G. K. Burgess...	Sci., 62	11	Apr. 5, 1907
Critical Ranges A_2 and A_3 of Pure Iron....	G. K. Burgess and J. J. Crowe.	Sci., 213	56	Sept. 22, 1913
Correlation of the Magnetic and Mechanical Properties of Steel..............	Charles W. Burrows...........	Sci., 272	38	Mar. 29, 1916
Notes on the Microstructure of Iron and Mild Steel at High Temperatures........	Henry S. Rawdon and Howard Scott......	Sci., 356	9	Mar. 15, 1920
The Strength of Reinforced Concrete Beams, Results of Tests of 333 Beams (First Series)................	Richard L. Humphrey and Louis H. Losse.....	Tech., 2	200	June 27, 1911
Surface Insulation of Pipes as a Means of Preventing Electrolysis................	Burton McCollum and O. S. Peters.........	Tech., 15	44	Jan. 5, 1914
The Determination of Phosphorus in Steels Containing Vanadium...............	J. R. Cain and F. H. Tucker.....	Tech., 24	11	May 17, 1913
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Result of Some Compression Tests of Structural Steel Angles..............	A. H. Stang and L. R Strickenberg.........	Tech., 218	17	Aug. 3, 1922
Effect of Heat-Treatment on the Mechanical Properties of One Per Cent. Carbon Steel..............	H. J. French and W. G. Johnson.	Tech., 206	31	Dec. 27, 1921
Manufacture and Properties of Steel Plates Containing Zirconium and Other Elements..............	G. K. Burgess and Raymond W. Woodward.	Tech., 207	54	Feb. 1, 1922
Thermal Stresses in Chilled Iron Car Wheels......	G. K. Burgess and R. W. Woodward....	Tech., 209	34	Mar. 18, 1922
Standard Gauge for Sheet and Plate Iron and Steel..............	....	Circular 18	....	....
Metallographic Testing..............	....	Circular 42	....	....
The Testing of Materials..............	....	Circular 45	....	....
Invar and Related Nickel Steels..............	....	Circular 58	....	....
Some Unusual Features in the Microstructure of Wrought Iron..............	Henry S. Rawdon	Tech., 97	25	Sept. 20, 1917
Observations on Finishing Temperatures and Properties of Rails........	G. K. Burgess, J. J. Browne, H. S. Rawdon, and R. G. Waltenberg.........	Tech., 88	63	Apr. 28, 1914
Tests of Large Bridge Columns...........	J. H. Griffith and J. G. Bragg....	Tech., 101	139	June 27, 1918
Tests of Eighteen Concrete Columns Reinforced with Cast Iron..............	John Tucker, Jr. and J. G. Bragg	Tech., 122	....	....
Metallographic Features Revealed by the Deep Etching of Steel..............	H. S. Rawdon and Samuel Epstein.........	Tech., 156	24	Mar. 19, 1920
Tests of Bond Resistance Between Concrete and Steel..............	W. A. Slater, F. E. Richart and G. G. Scofield......	Tech., 173	66	Nov. 1, 1920
Five Tests of Building Columns...........	S. H. Ingberg, H. K. Griffin, W. C. Robinson and R. E. Wilson...........	Tech., 184	375	Apr. 21, 1922
Influence of Phosphorus upon the Microstructure and Hardness of Low-Carbon, Open-Hearth Steels...........	Edward C. Groesbeck........	Tech., 203	33	Nov. 21, 1921
Tensile Properties of Some Structual Alloy Steels at High Temperatures...........	H. J. French...	Tech., 205	18	Dec. 20, 1921
Physical Properties of Materials: I—Strengths and Related Properties of Metals and Certain Other Engineering Materials..............	....	Circular 101	....	....
The Structure and Related Properties of Metals..............	....	Circular 113	....	....

Electric Telemeter.—The development of a carbon-resistance type, remote reading and remote recording device for the measurement of stresses, strains and forces, has been brought to a point where satisfactory practical application in field and laboratory work is being made. The operation of the device depends on the fact that a stack of carbon disks, when subjected to pressure, undergoes a change of length as well as a change of electrical resistance, and means have been devised to make these changes reproducible with sufficient accuracy for many engineering instruments. The apparatus has been used for making photographic records of stresses in the stay cables in airplanes during flight, of strains in steel bridge members while trains were passing, and for various laboratory purposes, including the testing of structural members, such as duralumin girders for the Navy Department and cellular members of the Delaware River Bridge towers. It has the advantage that simultaneous records can be made of the strains in different parts of a structure, the recording apparatus being placed at a convenient point while the elements that are attached to the members are placed as desired, the necessary electrical connection between them being made by three conductor leads which may be several hundred feet in length if necessary. A forthcoming *Technologic Paper* by Messrs. B. McCollum and O. S. Peters will describe the apparatus and its applications in detail.

7.—Conclusions

The speaker has not attempted to discuss exhaustively the subject of steel for engineering structures. The object has been twofold: First, to emphasize somewhat the metallurgical features of some of the broader aspects of the problem and the importance of associating the metallurgist with the engineer in the solution of problems dealing with steel for structures; and, second, to outline briefly a statement concerning some of the investigations in this field recently completed or in progress at the Bureau of Standards. An opportunity has not been given to verify all the historical statements and they are set forth with reserve. In Table 6 is given a list of publications of the Bureau of Standards relating to structural steels.

In the short time available for the preparation of this paper, the speaker has had the co-operation of several of his colleagues as mentioned previously. He is also indebted to Messrs. P. D. Merica and H. T. Morris for information on alloy steels, and to Messrs. W. Spraragen and F. P. McKibben for certain facts relating to welding.

RADIO AND RESEARCH

By Otto B. Blackwell,* Esq.

The civil engineer, presumably, is not particularly fond of vibrations. They fatigue materials and injure structures. To the communication engineer, however, vibrations and waves which vibrating bodies send out are an all-important subject.

In Nature, there are two types of vibrations and waves: First, what may be called mechanical vibrations and waves; and, second, electro-magnetic vibrations and waves. Radio telephony, as does all telephony, begins with mechanical vibrations, either speech or music.

Without considering what these systems of vibrations mean, the question of interest is that it is often desirable to transmit the effect of these mechanical vibrations to a distance. Mechanical waves will not serve this purpose, because they travel only a little more than 1 000 ft. per sec., and are dissipated rapidly as they travel.

With the ordinary telephone apparatus, however, these mechanical waves are translated into electro-magnetic waves at the sending end, and are transformed back again into mechanical waves at the receiving end. These electrical waves are made to have as closely as possible the same form as the mechanical waves which cause them. Probably the average individual, who has not studied electrical problems, has imagined, when he looked at a telephone line along a country highway, that the voice waves were inside the wires somewhat as a liquid inside a pipe. It is true that there are electrical currents in the wires, but the energy of the electro-magnetic waves is largely outside surrounding the wires. It is necessary to imagine invisible waves filling all the space around the wires, and with open-wire telephone and telegraph circuits, extending a distance of several feet from them, but guided by the wires to the place to which it is desired such waves shall go. It is on this principle of guided electro-magnetic waves that the tremendous networks of wires which make up communication systems have been built.

A fundamental characteristic of vibrations and of waves is that they have characteristic frequencies. When the speaker stated that the mechanical waves were turned into electrical waves of the same form, he meant that the electrical waves contain the same frequencies and in the same relative amounts as the mechanical waves. Although these electrical waves of the comparatively low frequencies used in speech and music are readily guided along the wires, it is comparatively difficult to separate them effectively from the wires so that they will spread into space.

If, however, very high-frequency electrical waves are generated, much higher than those in the voice or in music, and if these waves are allowed to oscillate in particular wire arrangements known as an antenna, then a considerable part of their energy may become separated from the wires and spread into space. Furthermore, it is possible to make the high-frequency waves carry a low-frequency telephone or telegraph message along with them.

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It is not necessary, for the purpose of this paper, to go into detail as to the methods by which the high-frequency waves can be made to carry waves of low frequency. In brief, it consists first of generating high-frequency oscillations, and then controlling them so that the magnitude of the high-frequency oscillations which are transmitted into the antenna varies in accordance with the variations of the low-frequency waves. At the receiving point, a very small amount of the energy is picked up, amplified without changing its form, and then is "detected", that is, its high-frequency part is smoothed out, leaving the low frequencies which were in the original telephone or telegraph message. The particular message desired is separated from other messages that may be in the air at the same time, provided the high frequencies with which it is transmitted are different from those of these other messages, by setting up electrical circuits which will receive only the high frequencies involved in the desired message.

With this brief outline of some of the fundamental facts of radio, it is interesting to consider the question which is continually being asked—what part will radio have in the communication art, what will it contribute to the public welfare?

It is evident that radio is confined to certain fields. Radio telegraphy between ships and from ship to shore has already become commonplace. Experiments have been conducted for several years in radio telephony by the American Telephone and Telegraph Company. A radio station was established at a point in New Jersey, and through it telephone subscribers as far distant as San Francisco and Los Angeles, Calif., have been connected by wire to the station and thence by radio to ships at sea several hundred miles from the radio station. Commercial operation of such a system depends on the solution of economic and commercial questions.

Radio is of peculiar importance to all classes of moving vehicles. It furnishes a means by which the airship may be guided directly to its destination. It can act as a beacon and guide to ships approaching the coast. The radio telegraph is already carrying a large volume of telegraph business from one continent to another.

The most interesting service to which the radio telephone undoubtedly will be applied is the connection of the wire telephone system of America to that of Europe and other continents. Communication over such distances was first shown to be possible by the tests of the engineers of the Bell Telephone Company in transmitting from Arlington, Md., to Paris, France, and to Honolulu, Hawaii, in 1915. Engineers are probably familiar with the experiments conducted on January 14, 1923, by co-operation between the American Telephone and Telegraph Company and the Radio Corporation of America, in which speeches were successfully transmitted from New York City and heard by an audience in a suburb of London, England.

Radio is peculiarly fitted for broadcasting, in that messages from one station may be picked up by any number of people within range of it. Although much of the interest in radio broadcasting is undoubtedly due to its novelty,

there seems to be no question but that it will be developed into an important permanent addition to the present means of instruction and entertainment.

Some of the fields for which radio is particularly fitted, and in which it gives, in many cases, an important service that in no other way can be obtained, have been mentioned. To consider the part radio will play in the bulk of communication that civilized communities require, it is necessary to appreciate the inherent nature of radio, as compared to wire transmission.

It is possible to communicate by radio with places where wires can be extended only with difficulty or not at all, and of reaching in a wide area at one time all those who care to listen. It is these advantages which make it of great value. It has limitations, however, as privacy can be obtained only with great difficulty and expense; it is affected by weather conditions, and it is, in general, an expensive means of transmission. Most important of all, however, is that the number of radio messages that may be transmitted simultaneously in any region is limited by the number of different carrier frequencies that may be used without interference. Although radio has only begun to give that service which must be required of it, there is considerable conflict between those who wish to use it, in obtaining proper carrier frequencies or wave lengths on which to operate.

The guided wave has the limitation that it is necessary to set up, operate, and maintain elaborate wire systems. It has the advantages, however, that an unlimited number of such paths may be set up, private, reliable, and economical.

An interesting illustration of this is a type of cable through which 1 200 simultaneous conversations can be conducted. Radio and wire service, therefore, supplement each other. The guided wave method must be depended on to carry the great bulk of communication required by civilization particularly in well developed regions. For broadcasting, for communicating with ships at sea and with other moving vehicles, perhaps for operation in various sparsely settled regions, for carrying a part of the telegraph traffic to Europe, and, finally, probably as a means of connecting the telephone systems of Europe with those of this continent, it is to radio that one must look.

Another phase worthy of mention is the relation of research to the radio art. When radio is mentioned, the name Marconi generally first comes to mind. Marconi, however, and the men who were experimenting at that time, were building a superstructure on a foundation which had been laid by three mathematical physicists, all of them teachers, Maxwell, Poynting, and Hertz. To these three mathematicians and physicists the world is indebted for building the foundations of radio, and of all electro-magnetic wave action.

The thermionic vacuum tube is the outstanding feature of radio apparatus. It has been constructed in sizes ranging from small tubes to those capable of handling 15 or even 100 kw. The thermionic tube is an instrument of wonderful sensitiveness, precision, and flexibility. In every part of the radio art it finds a field.

The underlying phenomena on which it is based were discovered by Edison. It was first thoroughly investigated and analyzed by O. W. Richardson (at

Cambridge and Princeton Universities) and put to practical use as a radio detector by Fleming. De Forest added to it the so-called third member or grid which began developments that have brought it to its present position. However, to develop it properly and disclose its capabilities from that point required more than the resources or the abilities of a single individual or those who could experiment only in a small way. It was fortunate that in two of the large industrial organizations, elaborate development and research organizations had been formed in which are combined the mathematician, the physicist, the chemist, the engineer, and all the necessary machinery for thorough study. In no other manner possible, it is believed, could the work of bringing it to its present position have been done.

Such organizations do not take the place of the isolated worker or the small research groups who are working together, particularly in the technical schools and universities. These seekers after fundamental truths frequently lay the foundation on which later work must build. It is believed, however, that these large research and development organizations are among the most potent agencies for the advancement of the arts necessary to civilization.

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TECHNICAL PAPERS PRESENTED AT THE ANNUAL MEETING, JANUARY 19, 1923

CITY PLANNING

REGIONAL PLANNING

By Nelson P. Lewis,* M. Am. Soc. C. E.

Early attempts at city planning were very limited in scope, having been confined almost entirely to projects for civic centers, many of which were ambitious, but few, if any, ever were completed. Subsequently, plans were made for particular and restricted areas of cities, most of them having been for new surburban real estate developments. In very few cases, even yet, have plans been made for the more orderly development of towns or cities as a whole, including an effort to correct some of the obvious mistakes due to the haphazard growth of the older built-up portions, as well as those where development could still be directed along more rational lines, with better adaptation to topography.

Most of these plans have been the results of efforts of groups of private citizens, or of civic or commercial organizations, and, lacking formal adoption by competent municipal authorities, they have not been translated into official and binding plans. Many planning commissions and boards have been created, some to be starved by inadequate appropriations, some to be abolished by the local authorities which created them. Others are functioning and rendering valuable service, especially in controlling the character of new developments, both within and without the city limits. Emphasis should be placed on the words, "without the city limits", as indicating a new and growing realization, in many instances taking the form of statutes, of the fact that it is useless to talk about correcting defects in the existing city if this same lack of intelligent planning is allowed to proceed in the territory which will soon become part of the city. Many cities, in their special charters, or by general city law, have been given the power to control the subdivision of property not only within but for some miles beyond their corporate limits.

Even the most intelligent planning has been predicated on the idea that the city is to extend outward and ever outward, that it will continue to absorb one suburb after another, or if it cannot annex and assimilate them, that it will spread over the unoccupied land between it and them. The result of the decennial enumeration is awaited with eagerness and if it does not meet the expectations and gratify the ambition of the town for bigness, a recount is demanded. This unbroken expansion, although jealously maintaining the old centers, results in the most serious difficulties in supplying transit within the city and in accommodating those whose occupation requires them daily to enter and leave the business district. The transit system is likely, as in New York City, to be developed in such a manner as to aggravate these conditions still further, so that the concentration of population in all large cities is becoming a serious menace, and the problem is fast becoming one of decentralization.

How are the cities trying to cure the conditions resulting from the unwholesomely rapid growth of the past few decades, a growth for which they

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were not prepared and which has brought with it great congestion in housing and traffic, so that in the homes, especially those of the poor, conditions are unfavorable to health and morals, and the use of the streets involves serious risk of physical injury? Scarcely a week passes without some new proposal for relieving not only existing congestion but also for meeting that which will come with further increase in numbers, accompanied, doubtless, by further development of nervous excitability and further decline in health and morals. New streets, over or beneath those existing, or even cut through intensively built blocks at enormous cost, are proposed to care for existing and coming traffic. New rapid transit lines are urged, located so as to bring more and more people to existing centers of finance, business, and amusement. These proposed changes are doubtless necessary to meet or to cure existing conditions, but the arguments in their favor nearly always refer, with more or less pride, to the increase in population, in business, and in wealth, which future years will bring. There is almost always an unconcealed conviction of the glory of mere bigness. There is seldom a suggestion of the need of trying to prevent the further development of conditions which render the problems still more difficult of solution. Larger areas must be studied and instead of beginning with present centers and providing for expansion outward, absorbing one after another of outlying towns and villages, it is time to begin at the outer edges of a great metropolitan district, to study existing communities and strive to encourage the development of their centers, to create new social, commercial, and industrial centers, and strive to protect what is worth saving from being drawn into the vortex at the big center and absorbed bodily by it, with no line of demarcation and with no barrier to the steady outward movement of population.

This is what the speaker has in mind when he refers to Regional Planning. The idea is not new. Under quite a different name, the need of such planning was emphasized by Ebenezer Howard at the close of the Nineteenth Century, especially in his book on "Garden Cities of To-morrow". This was soon followed by the establishment of the first "garden city" at Letchworth, England, about thirty miles from London. The idea appealed strongly to the English people, who have created a number of new municipal units which, although within a metropolitan territory, are designed to be largely self-contained, not having one industry, but a variety of different industrial establishments which tends to insure against the serious situation likely to develop in a single-industry town as the result of a bad depression or the cessation of activity in its particular industry. The avowal of such a purpose may cause protest, the kind of protest voiced by certain municipal officers or by local boosters already referred to, who protest the results of the Federal census.

The establishment of such new, self-contained, centers, however, will fail of its purpose unless they are protected not only against their own over-growth but also against the encroachment of other similar centers or of the great city of which they may be satellites. The British garden cities have insured themselves against such a fate by acquiring rings or zones of wooded or agricultural land which, owned by the town, can be made revenue-producing by

scientific forestry or through leasing or can be devoted to public recreation. The British Town Planning Act, applying to the entire Kingdom and administered by one central authority, affords an excellent medium through which such a policy can be carried out by those towns that wish to adopt it, even though there is a noisy minority in opposition.

Another conspicuous feature and advantage of regional planning is the opportunity that it offers to co-ordinate principal highways or traffic routes so that communication with the big center and between the subordinate centers may be direct and of ample capacity. In developing such a comprehensive system, the time has come when account must be taken of the extraordinary development of the transportation of goods and passengers on public highways, by means of motor trucks and motor stages. This development will force the provision of separate routes, or, at least, of separate roadways, for vehicles of this kind.

The idea of regional or metropolitan planning has been very slow in developing notwithstanding the object lessons which have been afforded by other municipal undertakings in which co-operative action proved to be necessary. Perhaps this is nowhere more forcibly illustrated than in the Metropolitan District of Boston, Mass., where, years ago, what are now nearly two score cities and towns, found it necessary to create Metropolitan Commissions for the development of their water supply, their main drainage, and their park systems. In the case of planning for more orderly growth, however, more convenient means of communication between different parts of the District, and for some means of controlling the use of private property which will be fair to each municipal unit, no machinery has yet been devised.

In New York State, Buffalo, the Tonawandas, Niagara Falls, and other near-by towns are trying to work out a regional plan for the Niagara Frontier District, which will involve even international problems, as the plans must necessarily include connections with the Canadian side of the Niagara River. A Los Angeles County Regional Planning Conference has been organized through which it is hoped that the group of towns in the Los Angeles District and the territory lying between them may be considered as a whole. At the fourth meeting of the Conference, held on September 16, 1922, what were designated as specifications for a regional plan were agreed on, in which some of the fundamentals of such a plan are tersely expressed. Among other things, emphasis was placed on the need of locating regional highways which would by-pass congested business centers so that through travel should not be subjected to the congestion of local business, nor should a large volume of through travel add to local business congestion; there should be a minimum of cross streets along main traffic arteries, long blocks along principal thoroughfares being encouraged; local roads should not cross parkways and boulevards at grade, if this could be avoided; population centers and sub-centers should be connected so as to permit rapid movement of passengers and freight between them; railroad grade crossings should be eliminated as rapidly as economic conditions permit, etc.

By far the most comprehensive project for regional planning which has yet been undertaken is "The Plan of New York and Its Environs", in which it is proposed to include an area of no less than 5 500 sq. miles, located in three States, with a population of approximately 9 000 000, according to the census of 1920. It will include, in addition to the present City of New York, with its five counties, five additional counties and parts of two others in New York State, eight counties and part of a ninth in New Jersey, and a part of one large county in Connecticut. The special difficulty and the delicacy of the problem are largely due to the fact that there are within the area under consideration nearly 400 different political units—States, counties, cities, towns, villages, boroughs, and townships. No one municipal corporation could undertake the preparation of a plan for such an extensive area without arousing jealousies and the suspicion of imperialistic designs on its smaller neighbors. It follows that a project of this magnitude can be undertaken only by an institution or a group of individuals which has no official connection with any of the political units which would be affected. The Trustees of the Russell Sage Foundation, which was established for the express purpose of "the improvement of social and living conditions", concluded that one of the most effective ways in which this object could be promoted would be through the preparation of a comprehensive plan for the future development of the district of which New York City is the center. A Committee on Plan of New York and Its Environs was appointed under the Chairmanship of Mr. Charles D. Norton. At a meeting held in the Engineering Societies Building, at which the first announcement of this plan was made, the justification for ignoring political boundaries in such a study was admirably stated by Mr. Elihu Root, one of the speakers, as follows:

"A city is a growth. It is not the result of political decree or control. You may draw all the lines you please between counties and States, a city is a growth responding to forces not at all political, quite disregarding political lines. It is a growth like that of a crystal responding to forces inherent in the atoms that make it up."

There is probably no precedent for the manner in which the work of this Committee was organized under four separate divisions:

(1) The Physical Survey, which first undertakes to visualize the problem, mapping existing topographical conditions, showing all transportation facilities, public utilities already developed, the density and distribution of population, provisions for recreation, and all local schemes of improvement in progess, or contemplated.

(2) The Economic and Industrial Survey, analyzing the fundamental reasons for the existence of this great center of industry and commerce, and with an inquiry into the economic and occupational activities creating populous districts and following population.

(3) A Legal Survey, including the study of existing laws in the several States or their subdivisions, which control or affect a plan for the area.

(4) A Survey of Social and Living Conditions, which would bring out clearly those factors having a direct bearing on human values and making for health and satisfactory surroundings.

The great concentration of population about New York City may be a source of pride to those who like to think and talk of it as the largest city in the world, but it involves many serious physical, economic, and social problems. In studying the past and probable future population, the total area has been divided into three districts: (1), designated as the Urban District and consisting of the present City of New York, with Hudson County and the City of Newark, in New Jersey, having an area of about 360 sq. miles and a population of 6 700 000; (2), the Suburban District, including all of Nassau and Westchester Counties in New York State, all of Union County, Essex County (outside of Newark), and parts of Passaic and Bergen Counties, in New Jersey, and the eastern part of Fairfield County, Connecticut, having a combined area of about 1 170 sq. miles and a population of 1 360 000; and (3), the remainder of the total area, comprising about 3 970 sq. miles, which is called the Rural District, with a population of 940 000.

The increases in population during the census periods since 1850 have been plotted for each of these districts and the curves projected forward to the end of the Twentieth Century. From them, it appears that at the close of the Twentieth Century the Urban District will contain 20 000 000 people, the Suburban District 13 000 000, and the rural district 4 000 000. The total population for the entire area will reach 20 000 000 in 1960 and 37 000 000 in 2 000. It is interesting to note that the last named total is equal to that of the present combined population of all the Atlantic seaboard States from Maine to North Carolina, inclusive. If these forecasts should be verified, the average density of population in the Urban and Suburban Districts combined would be equal to the present density in the Department of the Seine, but it makes a great difference whether such density extends over an area of 1 530 sq. miles or over a restricted area of 185 sq. miles, which is that of the Department in which the City of Paris is located. The speaker hopes that these estimates will prove to be incorrect, but they appear to have been confirmed, at least for the next two decades, by estimates of future population of the present City of New York made by the New York Telephone Company, the careful forecasts of which heretofore have been found to be quite accurate. The Company's estimate for 1930 is slightly less than that shown by the curves referred to, and that for 1940 is slightly greater. Although the uneven distribution of population in the large area is striking, the same holds true, to a remarkable degree, in the present City of New York. The New York Census Committee has called attention to the fact that 22.6% of the city's population lives on 1.6% of its area and that 68.8% lives on 10% of its area.

The purpose of this paper is simply to emphasize the need of regional planning. It would be impossible, within reasonable limits of time and space, to describe the studies thus far made and those proposed in connection with the Physical Survey with which the speaker is more particularly concerned, to say nothing of the other divisions of the work. The general scope of the investigations, and the manner in which the results are portrayed, will be indicated by the following brief list of the maps and plans completed and in progress:

I.—Five maps of the entire area, on a scale of 1 mile = 1 in., showing (*a*) general topographic features; (*b*) arterial highways, existing and proposed; (*c*) present and suggested parks and parkways; (*d*) railroads serving the district; and (*e*) sources of water supply and methods of sewage disposal. These maps are supplemented by twelve sectional maps, on the same scale, showing the principal highways, parks, and other open spaces.

II.—A series of maps and charts indicating the distribution and the relative densities of population throughout the entire area, with forecasts to the end of the Twentieth Century. These maps and charts indicate how unevenly the population is distributed, even within the central area.

III.—Maps showing the principal improved roads; the trunk-line highways, as located, and reduced to a theoretical diagram; the proposed motor-truck routes and the possible stages in their development from or in connection with existing roads; the traffic density on present highways, the result of counts, showing to scale the maximum number of vehicles per hour.

IV.—Transportation, including city transit: The trunk-line railroads serving the district; the passenger service, as indicated by the number of trains daily; the time zones at intervals of 15 min. from New York terminals; the commuting zones for 5-cent differences in one-way trips at commuting rates, based on 300 round trips per year; and the transit system of New York City and contiguous territory, showing subway and elevated lines, surface railroads, and bus lines.

V.—Park and recreation facilities: The existing public parks and suggested additions; the lakes and reservoirs which under proper sanitary control could be made available for recreation; the canals and waterways which could serve the same purpose; the wooded areas available for wild parks or forest reserves; the areas suitable for public camping grounds; diagrams showing park areas in relation to total areas and to population; and maps showing areas held privately as golf and country clubs in comparison with those free to the public.

VI.—Port and industrial development plans showing existing facilities and projects under consideration; areas zoned for industrial use; maps showing, for each county, the number of power plants and their average capacity.

VII.—Map showing incorporated places, mapped and zoned areas, indicating the extent to which the zoning idea has spread.

VIII.—Maps showing pollution of harbor waters in the central area and the location of sewer outlets and of sewage disposal plants.

IX.—A series of plans and sketches showing possible methods of traffic relief and additional traffic facilities in the most congested areas.

X.—A series of aerial maps and of oblique aeroplane views which portray existing conditions and are an invaluable aid in regional planning work.

An attempt has already been made to indicate the purpose of regional planning, especially where there are great centers of population. This purpose may be briefly summarized as follows: To counteract the tendency to excessive concentration of population and industrial activity in certain spots; to simplify the problem of transit between different parts of the area; to bring facilities

for receiving and shipping goods to all parts of the region; to establish a method of controlling the use of private property, consistently and equitably applied through the entire district, by the adoption of what might be called regional zoning; to locate places of public recreation so that they will be within easy reach of all; to relieve present congestion, which has been aptly described as "the crowding of streets by traffic, the crowding of lots by structures, and the crowding of rooms by people". If these results can be attained, it seems reasonable to predict that general health will be improved, a spirit of neighborliness will be promoted, the nervous strain due to tiresome journeys to work and back, under conditions often indecent, will be abated, children and adults will acquire that wholesome zest coming from closer contact with Nature, political dangers of revolutionary temper and mass action will be lessened, and much of the present economic waste will be avoided.

THE ENGINEER AND CITY PLANNING

By George H. Norton,* M. Am. Soc. C. E.

It has long been accepted that the engineer is essential to the planning of certain phases of community development. For sewerage, drainage, and water supply, his services have been indispensable, even from the earliest developments. As a surveyor he has had influence, at times, in the laying of the general plan of highways, which has directed the future development of a city street sytem. His position has been essentially that of a hired man assigned for specific purposes, with little differentiation between his highest professional skill and his ability as a surveyor.

In Government surveyed areas, the rectangular system has imposed enduring hardships on many cities, ameliorated, in some fortunate circumstances, by the imposition of diagonals where topographic conditions had induced the aborigines to establish reasonable trails, later followed by the pack train and the pioneer wagon, until they were so well established as highways as to maintain their integrity. In some of the older Eastern cities, devoid of dominating topographic conditions, too often this casual development, through trail and road to street, has been without control by features warranting the devious street plan for a modern city. However, there are excellent examples of sound judgment and foresight in the original plans of some cities. Perhaps, to-day, there is not a proper appreciation of the skill and courage of those who more than a century ago went into the practical wilderness and prepared the ground plans of cities, which have reasonably sufficed until such cities have grown in size far beyond that of any city existing on the American continent at the time of the original platting.

If there had been adequate means for the dissemination of engineering knowledge, the broad ideals of the Washington plan might have been extended beyond the moderated application to Buffalo, N. Y. This influence probably came to Joseph Ellicott who was in charge of the Buffalo improvement, through his brother who was engaged with Pierre L'Enfant in planning the City of Washington. As has been stated, this failure in dissemination of advanced planning was due to the lack of engineering publications and of that personal contact so valuable in this and other similar societies.

Having in mind this unfortunate past condition, it is encumbent upon the Profession to review the situation and meet the modern planning problem as it has met others.

Large numbers of the older generation of engineers have been associated at some time, and in some way, with railroad location, construction, or subsequent operation. They developed a high engineering conception of the problems involved and created standards which may guide. Much of this development came after, or perhaps more properly, was the larger element in creating literature and associations for the dissemination and discussion of the problems involved. When these, or other, engineers have entered municipal service, their

* City Engr.; Chairman Planning Comm., Buffalo, N. Y.

immediate and pressing duties have been the providing of sewerage, drainage, water supply, and pavements suitable for the existing areas and, perhaps, to look forward to the provision of such for adjacent territory. Assistance is seldom provided beyond that necessary to meet pressing demands, and more seldom is it realized that the field of the engineer should be wider.

The growing sentiment of a few decades ago, that American cities as municipal machines were not at par with other American achievements, led the ever-present reformers to demand changes in organization and administration. After having run the gamut of charters and methods to find that they do not change human nature, there has been a sudden awakening to the fact that municipal structures have simply grown from the demands of commerce, industry, and transportation along lines dictated by the especial needs or convenience of each and without thought of the mutual relations between them. They have grown under the stimulus of varied business impulses, not always harmonious in needs, and without definite plan or guidance. This realization apparently came first, not to the engineer, but rather to the artist and the architect who sensed the lack of harmonious development and the unnecessary clash and ugliness of many elements. Hence, it was only natural that the earlier movements in city planning were more along the line of the "City Beautiful".

The general awakening has disclosed the most necessary things for a well ordered city to be definite knowledge of its actual physical condition and a definite plan for its further development. The ills of the municipal body lie in its deformed and unguided growth rather than in its charter or ordinances, and its beautification should be in ordered arrangement and growth more than in surface embellishments. These fundamentals are fairly well accepted to-day, but the details of development are without accepted standards.

The complex problems of arrangement and co-ordination of the varied and often conflicting interests are so great as to demand the united wisdom of those versed in all their phases. There has been developed, therefore, the usual form of planning commissions composed of representative citizens whose united intelligence should cover the wide field, and to their assistance has been brought available engineering or other professional advice. Where such technical advisers have not been over-shadowed by the so-called practical element, scope for excellent results has been given, the balance of judgment of those representing the complicated interests formulating a policy which would give reasonable results when technically applied.

The alternative method of approach in making the engineer the dominating factor in the development of a plan with the representatives of varied interests acting as advisers has had less general application. Results alone can determine the relative advantages and much will depend on the wisdom and judgment of the engineer. He must have the support of the profession not only in sympathy, but more in the development of standards of this comparatively new field. This can be done only through discussion in engineering bodies and dissemination through the technical press.

Although the formulation of a definite plan for the guidance and orderly development of a city may have the highest talent and devotion in its preparation, such a plan will avail but little, unless it can be established.

The successful engineer has had his experience in presenting plans to the chief executive. Usually, the plans have been authorized by the directors who feel assured of the backing of the stockholders. The only questions for consideration are the fitness of the plan and the financial elements. In a city plan, however, there is the element of broad practical politics, not of the partisan kind, but in the truest sense. Municipal governments are most highly representative. The elected representatives in whom the ultimate authority lies may be ever so broad-minded and ready to assist in the development of a plan, but they cannot carry out any comprehensive one unless it is the will of a decided majority of their constituency.

The problem before the engineer entrusted with any planning project is, therefore, threefold: To prepare a plan which has features such as to appeal to the sound judgment of a large part of the citizens; to co-operate with the ever-present public-spirited citizens who are ready to assist in laying the matter fully before the whole electorate in such manner as to win their approval; and with such public approval, to go before the constituted authorities with the plan and a reasonable program of execution that the legislative and executive authorities may adopt and place under execution the most essential features. With the plan thus established in the minds of the people, there should be no reasonable fear that it, as a whole, will perish. Any live city has enough citizens of public spirit and foresight to see that the matter is brought to successive administrations, with public approval assured.

It is feared that some worthy plans made possible by the endeavor of the few, without general public acceptance, through publicity, may fail of achieving the early results which their intrinsic merit really warrants. Having in mind the essentials to the success of any city plan, the engineer interested in such is brought squarely to face the modern conception of his profession. He must realize that his function is not merely that of the trained investigator and establisher of fundamental facts, but rather that it has the wider limits of the human element. Assured in his own conclusions, he must be able to lay the reasons for such before the public in a manner to show their soundness and be able and willing to meet all objections with the convincing facts at his disposal.

The phases of City Planning particularly adapted to engineering analysis are many. The first step in any general plan may be designated as reconnaissance, or the broad survey of the resources and probable line of development of the city and its environs. Such a survey is necessary to the formulation of any comprehensive plan. The whole range of transit and transportation facilities, terminals, harbor development, and many other such questions will intrude themselves into any broad study, and, even if not directly included in the designation, must be given weight.

To-day, the most pressing demand for immediate consideration is apt to be for improvement of streets and the street plan to accommodate the traffic of motor vehicles. The civil engineers of a previous generation developed the

lines of transportation by the construction of railroads along carefully surveyed routes. To-day, although 1 000 000 freight cars may be loaded each week to pass over these lines, 10 000 000 motor vehicles are daily passing over streets and roads that were mostly laid out and determined before the construction of an automobile. There has been developed an entirely new mode of conveyance fitted for travel on highways which were laid out for other vehicles. The flexibility and adaptability of these modern vehicles is such that they may use the rural highways and many urban streets if only a reasonably hard and smooth surface is provided. Such a condition has forced on the whole country a road-building and paving industry and has developed new engineering standards in paving design. Except in the territory adjacent to large cities and on main connecting thoroughfares, the roadway wide enough for vehicles to pass safely provides accommodation for its traffic. Within the cities and on their converging highways, however, the newly developed transportation has been imposed on a street plan not designed for such purpose and bounded and limited by costly land and improvements which make difficult any material alterations. This condition now imposes on the engineer the more serious problem, not to design a thoroughfare system for specific needs, but to adapt the existing facilities to present demands so as to require a minimum of expansive changes.

It is not intended to enter into a discussion of the problems of street design, but rather to outline a few of them as typical of the engineering phases of city planning. No standard, as yet, may be considered established and cannot be until it is perfected through experience and analysis.

Widening Main Thoroughfares vs. Providing Parallels.—Most direct thoroughfares in cities have been occupied by surface traction lines with consequent business development. The location is such as to invite motor traffic with consequent congestion. Although surface traction cars interfere with the easy operation of thousands of motor cars, the latter delay thousands of passengers on the former. Diversion of traffic from such streets may be considered detrimental to the developed business interests. The cost of widening by land acquisition would generally be excessive.

Should these throughfares be widened or should parallels be developed to divide traffic?

Will such diversion injure adjacent business or endanger residence property on the parallels?

If such parallels for vehicular traffic are provided, should they preferably be immediately adjacent to developed main traveled streets or should they be intermediate between such?

Intersecting Streets.—Many cities have abolished at large expense railroad crossings at grade. To-day, at intersections of heavy-traffic streets, more accidents occur and more delays to traffic.

Are we to look forward to grade separation at such important points?

Where we continue to operate at grade, must we continue the alternate "stop-and-go" system or can the rotary, continuous system be developed with reasonable land acquisition?

Can the rotary continuous plan be adopted in preference to the reservoir system for holding the waiting vehicles?

In design of a rotary intersection requiring a material slowing down of traffic, can safety elements be introduced by the modification of grades or vertical irregularities?

Must separate provision be made for passage of long fire apparatus?

Vehicles and the Pedestrian.—What relative weights should be given pedestrian traffic and vehicular traffic when in conflict?

What is the effect on pedestrian traffic of long-radius intersection corners?

Is there a practical limit to the widths of pavements due to difficulty of maintaining parallel traffic lines and danger to pedestrians?

Are two parallel roadways preferable to a single one of their combined width?

Diagonals.—Are diagonals as essential to motor-vehicle traffic as they were formerly thought to be for mixed traffic?

Are not the complicated diagonal crossings often as much of a detriment to traffic as the longer routes of a rectangular system?

Do the advantages of radiating diagonals outweigh their tendency to traffic concentration?

These random problems arising in one phase of City Planning are herein noted as illustrative of the character of those details which demand engineering solution. To-day, engineers are becoming alive to them and will solve them as they have solved others.

When the engineer is brought face to face with City Planning, he must not only be able to master the technical details, as he has in other lines, but he must realize in the broader way that he serves, not a definite executive, but a complex public. He must have the wider vision clearly before himself and, with it, the courage and ability to impress these visions on the minds of the public. The line of reasoning with which he reaches conclusions must be so clear that it appeals to the average citizen. No plan may stand this test unless it is based on sound engineering fundamentals. No plan can come to execution unless it is understood and appreciated by the public. No plan can die which has been accepted by the citizens as sound and practicable.

The engineer who enters on City Planning must realize that his work is not confined to office detail, but that he must enter that broader field of the man among men. No other field to-day offers a fairer range for the highest development of engineering perspective or the formulation of new standards, and certainly none promises a fuller opportunity for the engineer to take his place as a leader of public thought, qualified to guide the development of those greatest institutions, the cities.

EXPERIMENTS WITH MODELS OF THE GILBOA DAM AND SPILLWAY

Discussion*

By Messrs. R. W. Gausmann and C. M. Madden†

R. W. Gausmann,‡ M. Am. Soc. C. E., and C. M. Madden,§ Assoc. M. Am. Soc. C. E. (by letter).¶—The writers are pleased to note the valuable discussion which this paper has brought out. It seems that all the discussors agree that models in whatever sense the word is interpreted, if properly used, may give valuable information for the preparation of designs of engineering work and, more particularly, for hydraulic structures.

In the early stages of the experiment, some doubt was expressed as to the usefulness of these models, and this doubt was intensified when it was found that models of different scales did not give identical results. It was only after many experiments with models of different scales that the writers felt safe in predicting that the behavior of the full-scale prototype would approximate the behavior of a small model.

The reference|| made by George G. Honness, M. Am. Soc. C. E., to the experimental models of the Boonton Dam, Cross River Dam, and Ashokan Reservoir Waste Weir are very interesting, as they show, particularly in the first two instances, that models have been used successfully in the development of hydraulic structures.

Robert F. Ewald, Assoc. M. Am. Soc. C. E., discusses** certain points that were not brought out in the paper. Experience has led the writers to believe that in this climate there is a tendency for exposed surfaces of concrete to disintegrate. All masonry surfaces, therefore, are to be faced with stone indigenous to this region, which is not susceptible to weathering. The floor of the spillway channels also is to be paved with sandstone and grouted.

On the dam, the edges of the steps are formed with stone from 6 to 36 in. in thickness, set on edge. These stones are 3 ft. deep (vertical) and from 3 to 5 ft. long (horizontal). As an added precaution, anchors not less than 5 ft. apart secure these edge stones to the cyclopean core. The treads are paved with stones from 3 to 36 in. and more in thickness (horizontal), an average depth of 21 in. (no stone is less than 18 in.), and varying lengths which must not exceed five times the thickness. The risers are faced with similar stones, except that the average width (horizontal) is 17 in. All the joints are carefully

* Discussion of the paper by R. W. Gausmann, M. Am. Soc. C. E., and C. M. Madden, Assoc. M. Am. Soc. C. E., continued from February, 1923, *Proceedings*.

† Authors' closure.

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¶ Received by the Secretary, January 18th, 1923.

|| *Proceedings*, Am. Soc. C. E., December, 1922, p. 1886.

** *Proceedings*, Am. Soc. C. E., February, 1923, p. 244.

grouted and, later, will be pointed. An excellent quarry has been opened near the Gilboa Dam from which large blocks of blue-gray standstone are readily obtainable. The minimum thickness of the stone placed to date is seldom less than 12 in. It is thought that this surface will be less subject to erosion and disintegration than concrete.

It will be noted from Fig. 4* that the grade of the channel is not excessive. The grade of the upper third is approximately 12.5%; the middle, 6.1%, and the lower third, 4.6 per cent. This diagram also shows that there is a considerable depth of water. In the part of the channel in the old stream bed, which is at the foot of the highest part of the dam, there is a depth of about 30 ft., due to a head of 6 ft. (163 cu. ft. per sec. per sq. mile). This depth due, in part, to the reconstruction of an old power dam, should provide an efficient water-cushion.

It is hoped that the theory of models may be developed more fully. At present, it seems as if practical difficulties would be encountered in making diminutive structures which would represent in detail the performances of their large scale prototypes, but it is possible that careful study might eliminate these difficulties and that it would be possible to reproduce in miniature, the destructive effect of Niagara Falls or the effects of the propelling charge of a 16-in. gun.

In conclusion, the writers wish to express their thanks to those who so carefully discussed this paper and also their appreciation for the assistance and encouragement given by those who either directed or assisted in this work, more particularly to J. Waldo Smith, M. Am. Soc. C. E., Chief Engineer until July, 1922, Thaddeus Merriman, M. Am. Soc. C. E., the present Chief Engineer, George G. Honness, M. Am. Soc. C. E., Department Engineer, and James A. Guttridge, M. Am. Soc. C. E., Division Engineer, all of the New York Board of Water Supply.

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* *Proceedings*, Am. Soc. C. E., December, 1922, p. 1510.

ENGINEERING GEOLOGY OF THE CATSKILL WATER SUPPLY

Discussion*

By Messrs. James F. Kemp, Thaddeus Merriman, Charles P. Berkey and James F. Sanborn†

James F. Kemp,‡ Esq. (by letter).§—This valuable paper summarizes the unusual experience gained in the application of geological investigations to a great engineering problem. The reading of it recalls many lessons which were driven home to those who shared in the early work; and, at least, one geological principle which to that time had not been appreciated at its true value in the United States. Geologists no less than engineers have profited by the work of the Catskill Aqueduct. In discussion, the writer would like to direct attention to one or two of these especial problems.

The selection of the most advantageous place at which to cross the Hudson River was one of the early and, also, one of the most important problems. As noted in the paper, a number of tentative explorations were made above and below the Storm King Crossing which was finally chosen. The explorations were made by wash borings, and profiles of the bed-rock bottom based on the results were prepared. The conclusion of those in charge, however, was that by this method the drill might easily come to rest on a large boulder and furnish unreliable evidence regarding the bed-rock unless the borings were checked by the diamond drill or the percussion drill to a depth sufficient, from the thickness and the nature of the rock penetrated, to preclude a boulder. It was learned that, for deep land borings or for borings under a river or other body of water, unchecked wash borings are of little value, especially in glaciated regions.

The geologists also had in mind the importance of finding a crossing for the pressure tunnel where there would be no faults. Breaks in the strata meant places of weakness which, under earthquake stress, might also be places of movement. Unless the selected location should prove practically impossible because of other considerations, such as disadvantageous approach, they desired to decide on a crossing without these structural lines of disturbance. Investigations led to the realization that there were many faults in the part of the Hudson Valley under exploration. Contrary, moreover, to the general belief regarding faults, those discovered were usually not of the normal type, but of the reverse type, and indicated that frequent over-thrusts had been produced in the past. The later and more detailed studies of Dr. Berkey in the West

* Discussion of the paper by Charles P. Berkey, Esq., and James F. Sanborn, M. Am. Soc. C. E., continued from January, 1923, *Proceedings*.

† Authors' closure.

‡ Prof. of Geology, Columbia Univ., New York City.

§ Received by the Secretary, January 24th, 1923.

Point Quadrangle and field trips with students in other areas of this region, have abundantly corroborated the early experience on the Aqueduct.

Geological considerations favored a crossing where the same kind of rock was exposed on both banks and presumably continuous beneath the river. The Storm King Crossing with its granite on both banks received early preference; but, in so narrow a gorge, one could not ignore the possibility or even the probability of a fault as the line of weakness which originally located the drainage. It was fortunate, however, that subsequent exploration, disclosed no fault beneath the middle and west side and only a small fault near the east bank, which fault fortunately passed upward into Breakneck Mountain and not into the river gravels and silts. Elsewhere, along the course of the Aqueduct many faults and weak crushed zones were found, and from the trouble caused by them, as described in the paper, they abundantly justified the original apprehensions.

The wash borings in the tentatively explored crossings above the Highlands disclosed no reason to expect unusual depth to bed-rock in the narrow Storm King Pass. Farther up stream the valuable record of the exploration to bed-rock at the Poughkeepsie Bridge, which were contributed by John F. O'Rourke, M. Am. Soc. C. E., in 1888,* also indicated the bed-rock from shore to shore, at about 140 ft. below high-water mark. The natural inference was that the granite at Storm King and Breakneck Mountain, which extended across the 2 000 ft. of river and which was the hardest rock in the stream from the Adirondacks to Cornwall, would furnish a gigantic riffle rather than an unusually deep depression. In the earliest work, this consideration gave added support to the choice of the Storm King site for the pressure tunnel. The reasoning that would have been followed at that time by practically every American geologist was that the bed-rock channel had been eroded by running water; that there must be a down grade to the sea; and that the land must have stood higher than it does at present with reference to sea level, so that the rivers could drain off. A progressively deeper channel was expected through the lower reaches of the river past New York City and out beneath the present ocean bottom. Geologists knew of the off-shore gorge of the Hudson, in the Continental Shelf, as it had been described years before,† but they were not prepared for the great depth, 800 ft. ±, which the drill subsequently revealed. This great depth led them to two possible conclusions, namely, the existence of a deep narrow gorge, deepening constantly to the south, past New York City to the sea, or, an over-deepening of the gorge at Storm King by sub-glacial erosion and the gradual rise of the bed-rock to and beyond Manhattan Island, as the southward moving glacier grew thinner and thinner and less effective as it approached the Terminal Moraine. The writer is of the opinion that the latter explanation is correct. Above the Storm King Crossing is the broad open bay of Newburgh, once undoubtedly filled with southwardly moving ice.

* "The Construction of the Poughkeepsie Bridge", *Transactions*, Am. Soc. C. E., Vol. XVIII (1888), pp. 199–215, especially p. 202.

† A. Lindenkohl, "Geology of the Sea-Bottom in the Approaches to New York Bay", *American Journal of Science*, Vol. 29, p. 475 (1885), and "Notes on the Submarine Channel of the Hudson River, etc.", *loc. cit.*, Vol. 41, p. 489 (1889); and J. W. Spencer, "Submarine Great Canyon of the Hudson River," *loc. cit.*, January, 1905, pp. 1–15.

The abrupt front of the Highlands crowded all the ice below the tops of the mountains into the narrow Storm King Gorge and created conditions exceptionally favorable for sub-glacial scouring and erosion. Access has since been gained to the records of the borings made by the Pennsylvania Railroad Company opposite 33d Street, Manhattan, for its tubes, but there is a gap of 1 200 ft. in mid-stream in which it cannot positively be stated that a deep narrow gorge may not exist, although that seems to be unlikely.* The bed-rock on the west side of the interval was 301 ft. below the surface, and that on its east side 287 ft. Nowhere else was the bed-rock so deep. Geologists still hope that some time a diamond drill boring may penetrate and demonstrate the bed-rock in mid-stream. At present, however, it may be stated that the Storm King Crossing and its great depth to bed-rock beneath the river has convinced the writer and many other American geologists of the soundness of the belief in the sub-glacial erosion by ice.

The borings in minor stream bottoms in the approaches to the Hudson River and the departures from it, and for the tentative sites for the great Ashokan Dam invariably revealed buried bed-rock channels, sometimes coincident with the general location of the present stream, and sometimes at distances from it. Geologists have thus been able to reconstruct an interesting system of pre-glacial drainage active when the land stood higher than it does to-day with reference to the sea level.†

The geological sections in the Hudson Valley, in the Wallkill Valley, and in the Upper Esopus Valley, are comparatively simple; but when the Rondout Valley is crossed, the section both in number of formations and in faulting becomes exceedingly complex. It was explored, therefore, with great thoroughness by the drill, and the results were accurately drawn in profile before bids for the sub-divisions of the pressure tunnel were invited. Contractors were thus enabled to bid with full knowledge of what they would find regarding the depth and character of rock. The geologists realized that the Binnewater sandstone was practically certain to be a wet formation. The precaution was thus adopted by the engineers of dipping down with the tunnel as they neared this sandstone and, after installing pumps, to tap the sandstone on the up grade. The water which rushed in, was thus promptly cared for, and no delay in the work resulted.

Many other individual problems are admirably set forth by the authors, to whom engineers and geologists everywhere are under a great debt. The problems selected for discussion by the writer are those, however, which occur to him as of especial interest and importance to both groups.

* In 1910, these data were placed in the hands of the late G. Sherburne Rogers, at the time one of the graduate students of Columbia University, and was the basis of the paper by him, entitled "The Character of the Hudson Gorge at New York City," which was published in the *School of Mines Quarterly*, November, 1910, pp. 26–42.

† "Buried Channels Beneath the Hudson and Its Tributaries," by the writer, *American Journal of Science*, October, 1908, pp. 301–323; "Geology of the New York City Aqueduct," by Charles P. Berkey, *Bulletin 146*, New York State Museum, 1911, which gives numerous local details. For a review of buried channels elsewhere in the region, see "Buried Channels in the Northeastern States," by the writer, *Proceedings*, Wyoming Historical and Geological Soc. of Wilkes-Barre, Pa., Vol. 14, pp. 1–20 (1913). These phenomena are of much interest to civil engineers in connection with dam sites, and many problems of water supply.

THADDEUS MERRIMAN,* M. AM. SOC. C. E. (by letter).†—Attention has been called by Joel D. Justin,‡ M. Am. Soc. C. E., to the general question of underground flow, and he has expressed a wish to know what theoretical investigations, if any, were made in order to determine the feasibility of the Devasega Dam site. The controlling reasons for the adoption of the site at Gilboa in preference to that at Devasego were:

First.—Sub-surface investigations at Gilboa showed this site to be much the better. No uncertainties such as those disclosed at Devasego were revealed by the borings.

Second.—The Gilboa site would furnish a larger reservoir with more storage and, at the same time, increase the available drainage area from 243 to 314 sq. miles.

The situation at the Devasego site was as follows: As stated by the authors, the preliminary borings had disclosed the existence of a large body of doubtful material about 30 ft. thick and 1 200 ft. wide. In order to determine the perviousness of this ground, a number of tests were made by pumping water into the drill casings. By noting the pressure at the top of the casing, the quantity of water pumped, and the rise of the ground-water table at other holes in the vicinity, it was possible to reach reasonable conclusions as to the continuity of the porous zone and its water-carrying capacity.

Twelve of these tests were made after the drill casings had been lifted and the drill holes in the rock had been completely filled with clay in order to prevent the escape of water through the rock joints. The results of these tests are summarized in Table 1.

TABLE 1.

Test No.	Length of test, in hours.	Rate of pumping, in gallons per minute.	Pressure at top of drill hole, in pounds per square inch.	Number of responses in other holes.
1	63	72	Negative	2
2	59	37	15	2
3	48	75	Negative	3
4	55	90	"	8
5	56	91	"	10
6	24	83	25	1
7	51	89	Negative	11
8	28	87	"	12
9	23	86	"	8
10	22	82	12	5
11	31	64	30	3
12	31	137	Negative	5

The tests, summarized in Table 1, showed that the doubtful material was exceedingly porous and could not be depended on alone to serve as part of any dam. For instance, Test No. 7 showed that 89 gal. per min. pumped for 51 hours—a total of 272 000 gal.—raised the elevation of the water-table in 11 other holes an average of 0.46 ft. over an area of about 15 acres. The most

* Chf. Engr., Board of Water Supply, City of New York.

† Received by the Secretary, January 24, 1923.

‡ *Proceedings*, Am. Soc. C. E., January, 1923, p. 130.

distant hole in which a rise was noted was 900 ft. from that into which the water was pumped. Although these tests did not quantitatively disclose the capacity of this material for carrying water, they did show that at many points, with little or no resistance, it would take from 80 to 130 gal. of water per min. through a 2½-in. pipe, and that this water would flow freely for long distances and over large areas.

Although the methods suggested by Mr. Justin may be applicable to cases in which sand and gravel have been uniformly laid down, they cannot be adapted to locations such as that at Devasego, or, in fact, to any location in a glacial deposit unless the facts as to the uniformity of that deposit are known.

The problem at Devasego was generally similar to that described by the authors at "The Tongore Alternative Site" of the Ashokan Reservoir.* The preliminary borings at this alternative site disclosed conditions which were interpreted as indicating a doubtful and undesirable situation. The site, however, offered such other advantages that further examination seemed to be desirable. A shaft, therefore, was sunk to the material which had been shown by the borings to be pervious. In commenting on the conditions at the time (1906), Dr. Berkey wrote as follows:

"The conditions reported in the new large shaft (Tongore) in the gravel beds now being penetrated, *i. e.*, at first 'no water', and then a little deeper an 'abundant flow,' I interpret as follows: It is not an isolated pocket or lens, else it would have carried water full from the first. It must be a fairly continuous porous zone with large feeding connections else it would run dry, and with easy discharge, else it would have risen above the first gravels. Therefore, it must be a rather well marked subterranean water passage or perhaps a porous zone of considerable extent. Such conditions it seems to me make an impervious core wall to bed-rock a necessity, and its construction a matter of considerable difficulty. In this site, because of the small cross-section of the ridge, there is little chance for the interlocking of layers or the blocking of the porous ones by a till barrier."

These two cases serve to illustrate the necessity of supplementing the results obtained by the ordinary wash-borings whenever the conditions are doubtful. They also serve to show that theoretical considerations alone are not to be depended on as trustworthy guides.

Charles P. Berkey,† Esq., and James F. Sanborn,‡ M. Am. Soc. C. E. (by letter)§.—The writers wish to express their appreciation of the comments that have been made by the engineers who have contributed to the discussion. Altogether important contributions have been made, and the writers willingly accept the corrections, criticisms, and additions.

In the beginning, it would have been possible to increase greatly the scope and detail of the paper. Many items of more than local or personal interest were deliberately omitted in order to keep the paper within moderate length and also to reserve the available space for more careful attention to certain items that seem to illustrate better its purpose.

* *Proceedings*, Am. Soc. C. E., September, 1922, p. 1544.

† Prof. of Geology, Columbia Univ., New York City.

‡ Cons. Engr., New York City.

§ Received by the Secretary, January 20th, 1923.

The writers have held strictly to the plan of laying a rather simple foundation picture of the nature of the enterprise, and the conditions under which it had to be developed. Following that, the major instructive geologic incidents and problems that seemed to promise a contribution of possible value to the Engineering Profession were treated. It was believed that examples of the interrelation and interdependence of geologic and engineering factors were exhibited so well in certain parts of this project that they might serve a good purpose in illustrating appropriate methods, splendidly effective co-operation, and successful solutions of many obscure and somewhat baffling natural conditions.

It is the writers' belief, based on a great many years of observation, that neglect of geologic factors or inadequate study of them is a common fault in a majority of engineering undertakings. Many serious blunders may be traced to this as a fundamental cause, and it is hoped that the illustrations given in connection with an important project, such as the Catskill Water Supply, which is now known to have been very successfully conducted, may be serviceable. There is no desire to over-emphasize the contribution of geology to that success; that it was a contribution of no little importance is so generally attested by the opinions of the engineers in charge and by the results secured that the writers feel fully justified in stating the facts and in separating the principal geologic problems as found in this work from the obscuring mass of other problems and data, so that one may the more clearly see their bearing.

The writers do not assume to claim that a geological study is the cure for all difficulties. Neither do they assume to suggest that geologic opinion is to take the place of properly organized exploration. This is a mistake commonly made. It is just as extreme and unreasonable as the attempt to ignore the geologic factors. It is not unusual to hear engineers say that even if a geologist is employed explorations must be made, as if that was some sort of legitimate reflection on the geologist and sufficient excuse for the engineer. Yet, that is exactly what should be done in the average engineering case. If he is competent, the geologist can indicate not only what kinds of explorations should be made, but also where they must be made to accomplish the most useful returns in the most economical way. He should be able, also, if he is familiar with the needs of the engineer, to interpret the data observable in the field and obtained by exploration, more logically and more reliably than one who is not thus trained. The geologist, therefore, should not be regarded as a substitute for exploration, or an excuse for loose methods, but an interpreter of geologic conditions, an aid in successful investigation, and a critical adviser in the matter of design, methods, and contracts that have to do with construction in the ground.

Many engineers of long experience become familiar with physical conditions and the laws of ground behavior. They are normally close observers and rigid reasoners and are exceedingly cautious in drawing conclusions. They are preeminently qualified in these respects for just such kind of work as falls also to the geologist; and it often happens that little more than support can be given to the conclusions already reached by such engineers. It so happens,

however, that it is not usually possible for a man in one great field of endeavor to become a master of other, even closely related, lines. He cannot feel certain that all its possibilities are met and that his conclusions are reliable. To such a man, a competent geologist can render real service. It sometimes happens that an engineer is not well enough informed or experienced to appreciate what the problem is, or even that there is a problem at all or that it can be solved, and, for this reason, among others, additional opinion is not asked. Sometimes, one has to ask permission to help such men, or one is asked to explain the cause of the trouble after it is too late for advice to serve any purpose.

The ideal situation is one in which the engineer, already comparatively well grounded in all the major features of the problem to be encountered, is still able to appreciate that a fuller or more critical study might materially improve the chances of success, or allow the design to be modified better to suit the conditions, make the contracts more definite, secure more economical treatment, or conduct the work on safer lines. Wherever this broad view is taken, and adequate consultation privileges are conferred on a competent, experienced geologist who appreciates the point of view and purpose of the engineer and will confine himself to the practical questions of the case, material service can be rendered in phases of the undertaking that cannot be reached any other way.

In an important case, where all the facts and conditions are not perfectly clear, the geologist should know enough not to give a final opinion without additional exploratory evidence; and the engineer should be wise enough not to treat an opinion as if it was a proven fact and then blame the geologist for mistakes which belong to both. The average responsible engineer has been found by the writers to be an unusually intelligent man who readily appreciates the distinction between facts of observation and inferences, and between conclusions based on close, logical reasoning and hypotheses based on more or less incomplete or inadequate data. All these things have to be dealt with, however, and it is peculiarly the province of geology to deal with many of the less conclusive hypotheses, not at all because the geologist wishes it to be so, or because it is his habit of mind, but simply because many underground conditions are obscure and because only a few of the many needed facts in a given case can be found by any method at any one's command. Thus, the geologist does the best he can with what he can get, in the belief that this, also, will be helpful.

The paper has been written largely to explain and illustrate that part of the work on the Catskill Aqueduct which normally came under the eye of the advisory engineering geologist. There is like work to be done by some one in every project of a similar nature. The writers are certain that a greater amount of such help should be obtained in most projects having to do with the ground, and they hope that the illustrations given by them, together with the comment made by those who have so liberally and instructively discussed the paper, may help enforce this observation and thus make the contribution something of educational value to younger men who, in the future, are to be responsible for large public undertakings.

THE COMPARISON OF CONCRETE GROINED ARCHES AS AN AID IN THEIR DESIGN

Discussion*

By Philip O. Macqueen, Assoc. M. Am. Soc. C. E.†

Philip O. Macqueen,‡ Assoc. M. Am. Soc. C. E. (by letter).§—The results obtained by the tests, made in 1905 by the Bureau of Filtration of Pittsburgh, Pa., on isolated groin units form a valuable contribution to the subject. Tests on full-sized groins, or even models of groins, are scarce, so that the data now published for the first time in the discussion‖ by Thomas H. Wiggin, M. Am. Soc. C. E., are particularly welcome. The results given by him in Table 5 indicate with a fair degree of clearness the general cantilever strength of a typical groined arch, and it is observed that this strength is sufficient to sustain approximately the usual full dead load of 2 ft. of earth, which the average arch is called on to bear. The failure of the arches having relatively thin sections at the crown is deserving of especial attention, as well as the general occurrence of the initial break near the center of the sides. Cantilever action, as noted by Mr. Wiggin, is unnatural in groined arch roofs, but nevertheless it forms an important factor of safety in many cases where joints in roofs have opened slightly due to contraction.

Mr. Wiggin has called attention to the statement made by the writer that "it will also be found that the average thickness decreases directly with the span," and has shown that this statement does not necessarily follow from the results given in Table 1.¶ It is true that the change in average thickness of roof shown in Table 1 does not directly follow the change in span, but this is due to the personal element which has entered into the various designs. For example, it will be noted that the average roof thickness for Arches Nos. 8 and 9 are high, principally on account of the very small depressions over the columns which the designers have used in these special cases. Other sudden changes in average roof thickness due to somewhat similar reasons will also be observed. However, there is a general tendency for the average roof thickness to decrease with the span.

The effect of change of span on the total quantity of concrete is difficult to determine and can only be shown by making certain assumptions. Table 8, therefore, furnishes data on a set of imaginary arches in which the dimensions are made to conform in general with those recommended by the writer on page

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* Discussion on the paper by Philip O. Macqueen, Assoc. M. Am. Soc. C. E., continued from February, 1923, *Proceedings*.

† Author's closure.

‡ Cons. Municipal and San. Engr., Washington, D. C.

§ Received by the Secretary, January 24th, 1923.

‖ *Proceedings*, Am. Soc. C. E., February, 1923, p. 251.

¶ *Proceedings*, Am. Soc. C. E., October, 1922, p. 1667.

TABLE 8.—DATA SHOWING EFFECT OF SPAN ON QUANTITIES OF CONCRETE IN GROINED ARCH RESERVOIR CONSTRUCTION.

No.	Clear span ($2a$), in feet.	Rise of intrados (b), in feet.	Crown thickness(t), in feet.	Rise of extrados (h), in feet.	Span center to center of columns ($2c$), in feet.	Thickness of square column ($2c$-$2a$), in feet.	Assumed height of reservoir roof above floor, in feet.	Clear length of column, in feet.	Volume in roof groin, in cubic feet.	Volume in column, in cubic feet.	Average thickness of roof groin, in feet.	Equivalent thickness of roof groin for volume in column, in feet.	Total average thickness (roof plus column), in feet.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1	10.0	1.667	0.5	1.083	11.250	1.250	18.0	16.833	67.969	25.528	0.537	0.202	0.739
2	11.0	2.000	0.5	1.250	12.333	1.333	18.0	16.000	83.701	28.432	0.553	0.187	0.740
3	12.0	2.333	0.5	1.416	13.417	1.417	18.0	15.667	101.169	31.459	0.562	0.175	0.737
4	13.0	2.667	0.5	1.583	14.500	1.500	18.0	15.333	121.186	34.499	0.576	0.164	0.740
5	14.0	3.000	0.5	1.750	15.583	1.583	18.0	15.000	142.972	37.590	0.588	0.155	0.743
6	15.0	3.333	0.5	1.916	16.667	1.667	18.0	14.667	167.074	41.860	0.603	0.147	0.750
7	16.0	3.667	0.5	2.083	17.750	1.750	18.0	14.333	193.425	43.782	0.614	0.139	0.753
8	17.0	4.000	0.5	2.250	18.833	1.833	18.0	14.000	222.043	47.040	0.625	0.132	0.757
9	18.0	4.333	0.5	2.416	19.917	1.917	18.0	13.667	249.796	50.226	0.628	0.126	0.754
10	19.0	4.667	0.5	2.583	21.000	2.000	18.0	13.333	286.943	53.332	0.650	0.121	0.771

1674.* It has been assumed that all the columns are square with special bases omitted and that the height of the reservoir from the floor to the under side of the roof at the arch crown is 18 ft. It has also been assumed that the floor of the reservoir is level and of the same thickness throughout.

It will be observed from Table 8, as stated by the writer on page 1671,† that the average roof thickness (Column 12) decreases almost directly with the span and that the total average thickness of roof plus column (Column 14) also decreases slightly with the span.

On account of its important bearing on the calculation of total quantities of concrete, the writer is glad that Mr. Wiggin has raised the question of the effect of span. Table 8 must be considered as lacking more or less in definite indications, as the arches are assumptions on the part of the writer, but it seems fairly safe to conclude that the change of span has relatively small effect on total quantities. As the span decreases, the volume of concrete in the roof decreases, but as the volume in the columns increases, the total volume remains practically the same. The principal saving, therefore, in using longer spans would be in form work, with the additional advantage of increased capacity in the reservoir.

Comparing Arches Nos. 21 and 30, Mr. Wiggin has called attention to the effect of the size of the pier capital on the average roof thickness. Making the pier capital for Arch No. 30, one-eighty-eighth instead of one-seventy-sixth of the roof area would decrease the average roof thickness from 0.675 to 0.663 ft. This is a decrease of only 2%, whereas the change in average roof thickness due to decrease of span from Arch No. 30 to Arch No. 21 is from 0.675 to 0.618 ft., or about 8 per cent. It appears to the writer, therefore, that in this case the change of span has greater effect on the quantities than the change of size of the pier capital.

As stated by Mr. Wiggin, it is absurd to carry the subject of theoretical economy to the extreme, and there are practical limitations in groined arches as well as in all other construction work. Considering the structure outlined in his paper, the writer would recommend the average economy which ordinarily is used in designing concrete work, for example, such as beams, columns, and retaining walls.

The steel reinforcement for groined arch roofs is a question that is probably discussed each time a new roof is designed. In practice, reinforcement is seldom used, although in certain instances the writer believes it is advisable, such as in the new Baldwin Reservoir for the City of Cleveland, Ohio,‡ in which the columns and spans are of unusual length. In the Baldwin Reservoir, single, straight, $\frac{3}{4}$-in. steel rods were placed along the perimeter of each groin adjacent to the crown, and the rods used were of such length that four groins in a group were joined together. Adjacent groups of four groins were not connected. The reinforcement was intended more for construction stresses and construction safety than for working stresses.

* *Proceedings*, Am. Soc. C. E., October, 1922.

† *Loc. cit.*, October, 1922.

‡ *Engineering News-Record*, November 30, 1922, p. 916.

In the discussion, attention is called to the use of groined arches in the floors of reservoirs. The writer is not in favor of using groined arches in this manner. Plain floors will be easier to place if the foundations are solid, and they can be designed so as not to involve extra concrete. If the foundations are not solid, the groined arches would be likely to open due to slight settlement and cause very heavy leakage.

The proper concrete mixture for groined arches is a subject for the most careful consideration, and the writer must admit his conservativeness on this question. The decision to use certain proportions does not guarantee a predetermined strength, as the quality and size of the aggregate and other factors are of equal or, perhaps, more importance. If possible, the proportions should be determined from actual tests. In the writer's opinion, the average ultimate compressive strength of the concrete developed in 28 days should not be less than 1 800 lb. per sq. in.

In conclusion, the writer wishes to state again that the various comparisons and approximate formulas discussed in his paper are intended to act principally as an aid in the design of concrete groined arches, and it is believed that the points noted in the paper and in the thorough discussion by Mr. Wiggin will be of assistance in this special field.

THE WATER POWER PROBLEM

A SYMPOSIUM

Discussion*

BY J. P. JOLLYMAN, ESQ.

J. P. JOLLYMAN,† ESQ.—Some of the phases of high-voltage transmission and some of its problems have been discussed interestingly by Mr. F. W. Peek, Jr.‡ and Professor Harris J. Ryan.§ The speaker will discuss this subject from the standpoint of operating companies which are confronted with increasing demands for electric energy, and are finding their sources of such supply being utilized more and more in the regions near the load. They are compelled, therefore, when dependent on hydro-electric energy, to reach farther and farther from their load centers for their supply. With this necessity for transmitting energy over greater distances, they are forced—if they want to keep their costs down—to the use of higher voltages. The economic situation in California has forced the operating companies to the use of 220 000 volts as the most economical solution of their problem.

The question of distribution of large amounts of hydro-electric energy in other parts of the United States has been discussed in connection with this subject. The water-power developments of Niagara, and the possibilities of the Colorado and the Columbia Rivers have been mentioned. However, the utilization of those powers and the distribution thereof to the places where there will be a demand for them will be dependent on the use of the highest transmission voltages.

The operating company, when confronted with the necessity of using a voltage higher than that which has heretofore been utilized, finds itself dependent on knowledge that has been acquired comparatively recently. There is no long period of experience with the highest operating voltages. The operating companies are just arriving at that stage, and they are dependent on the technical knowledge that is acquired by the researches made at the universities, of men like Professor Ryan, and his students. The operating companies can obtain experience with these voltages only after they have them in service. They cannot and must not invest millions of dollars in something that is unknown or untried. They must take a step in advance, they must be dependent on such knowledge as has been accumulated by recognized authorities.

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* Continued from February, 1923, *Proceedings*.

† Chf., Dept. of Eng., Div. of Hydro-Electric and Transmission Eng., Pacific Gas & Elec. Co., San Francisco, Calif.

‡ *Proceedings*, Am. Soc. C. E., November, 1922, p. 1766.

§ *Proceedings*, Am. Soc. C. E., December, 1922, p. 1859.

In behalf of the operating companies, the speaker wishes to express his appreciation of the time and money that has been expended in research by the manufacturing companies and the universities. Only by such means is it possible for the people of the country at large to enjoy the benefits of continually increasing supplies of low-cost energy which in California, at least, must be derived from water power and must be transmitted over continually increasing distances.

Papers.

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THE DESIGN OF STRUCTURAL SUPPORTS FOR TURBO-GENERATORS

Discussion*

BY GEORGE A. ORROK, M. AM. SOC. C. E.

GEORGE A. ORROK,† M. AM. SOC. C. E.—Since 1905, the speaker has been interested in the design of about forty steel foundations of various sizes. Most of the foundations built by the speaker's company are of the table-top type. Two other types used might be called the trestle type, in which the girders run athwartships of the turbine, and the girder type, in which two longitudinal girders not tied together rigidly, are used. In the last two types, the legs are bolted down, or an attempt is made to anchor them at the foot, which, in the table-top type, is not so necessary.

The total weight of turbine foundations should usually be adjusted to the weight of the turbine and condenser. Sufficient weight is added by concrete which is placed between the girders.

In the design of the table-top type, the deflection is kept less than about 0.006 in. Sometimes, a deflection of as much as 0.0013 in. in the frame of the machine will not cause serious trouble in its operation. Recently, a machine of 25 000 kw. capacity was placed about 1 in. above the steel cross-girder, at the middle bearing. Through some misadventure, the grouting worked loose, or disintegrated, and the steel wedges used had backed out a little, allowing the middle bearing of the turbine to drop about 0.0013 in. The turbine ran for a month or more in this condition until it could be dismantled and wedges again driven.

Whether the shaft must be level has also been a question. The speaker has noted cases where one end of the shaft was as much as 1 in. lower than the other. In these cases, a thrust bearing was used, and the turbine worked satisfactorily.

There are four methods of supporting a condenser. Formerly, a concrete pedestal was used, an expansion joint being placed between the condenser and the turbine. The concrete walls made repairs under the condenser difficult. About 1911, however, the practice was begun of hanging the condenser from the main girders, supporting the turbine on top of such girders, omitting the large expansion joint, and using expansion joints on the small water and air pipes. This made a good arrangement which is being used to a great extent at present.

In another case, spring beams were used between the columns supporting the foundation. The beams were designed so that they would spring sufficiently to

* Discussion of the paper by Edward H. Cameron, Assoc. M. Am. Soc. C. E., continued from February, 1923, *Proceedings*.

† Cons. Engr., New York City.

allow the condenser to take its proper place. This construction has been used for nine years, without any trouble. The spring support was introduced about the same time and has been successful.

The Westinghouse Company is bringing out a new type of steel foundation. This foundation is in two parts, which allows the condenser to be placed at right angles to the turbine, with the square, or oblong, foundation supporting the generator on one side, and the turbine on the other side, of the condenser. In this case, the condenser shell is made a part of the exhaust nozzle of the turbine itself, no large expansion joints are required, but smaller expansion joints are placed on the small pipe as before.

MEMOIRS OF DECEASED MEMBERS

NOTE.—Memoirs will be reproduced in the volumes of *Transactions*. Any information which will amplify the records as here printed, or correct any errors, should be forwarded to the Secretary prior to the final publication.

JOHN ANDERSON BENSEL, Past-President, Am. Soc. C. E.*

DIED JUNE 19TH, 1922.

John Anderson Bensel was born in New York City on August 16th, 1863. He was the son of Brownlee Bensel, whose ancestors came from Bruges, Belgium. His mother was Mary Maclay Hogg, the daughter of John Anderson Hogg, a Scotchman and lawyer, who was associated with Charles O'Connor, a leading member of the New York Bar about fifty years ago. Mr. Hogg was considered by Mr. O'Connor to be among the most brilliant and promising of his young assistants. Mr. Hogg's wife was a Miss Maclay, the daughter of a prominent clergyman of Scotch ancestry. In this, Major Bensel took great pride, showing a love for all the old Scotch customs and holding the virtues and sturdy characteristics of his Scotch ancestors in high esteem. Thus, his membership in the St. Andrew's Society was always a source of pleasure, and, for many years, he took an active interest in all its functions.

Mr. Bensel was the eldest of eight children, and at the age of twelve had many responsibilities thrust upon him on account of the death of his father. A sketch of his early life is a reminder of the wonderful growth of New York City in the past half century. Born in 24th Street, his family moved, when he was six years old, to 155th Street in the vicinity of Audubon Park, which was, at that time, the country-side far beyond the city proper. From there, he attended school far down town, the Twelfth Street Public School, celebrated for having turned out many notable men; later, he attended the "Friends School" on East 13th Street. This connection with the Quakers conveyed some lasting impressions, and he always retained a great admiration for them, their standards and ideals, the simplicity of their dress, and the spirituality of their religious exercises. At about his sixteenth year, the family returned to the city proper and lived for many years at 64 East 79th Street. The gap caused by the loss of his father at an early age, was fortunately filled by a mother of unusual attainments. A strict disciplinarian, she brought her young family up in an atmosphere of the utmost simplicity. Possessed of a cultivated mind and high ideals, and of unusually intimate knowledge of history and literature, she was qualified to supply the lack in the ordinary public school curriculum extant at that time. Although this effort of his mother to transmit something of her knowledge of the classics did not outwardly bear direct results, the boy's mind running on purely practical lines, the impressions were lasting and showed in his appreciation of everything beautiful. His artistic sense and his keen appreciation of beautiful things were not only evident in

* Memoir prepared by George H. Pegram, Past-President, Am. Soc. C. E., and John P. Hogan, Robert Ridgway, Charles W. Staniford, and William H. Yates, Members, Am. Soc. C. E.

his house and its furnishings, but in every structure that he had a part in designing.

Mr. Bensel was graduated from Stevens Institute of Technology on June 12th, 1884, with the degree of Mechanical Engineer. On June 21st, 1921, his Alma Mater conferred on him the honorary degree of Doctor of Engineering in recognition of his distinguished engineering service.

His first work after graduation was as Rodman in the Department of Public Works of New York City, where he was engaged on contour and property surveys for the proposed new Croton Dam.

On October 1st, 1884, Mr. Bensel was appointed Rodman in the Maintenance of Way Department, United Railroads of New Jersey Division of the Pennsylvania Railroad, and, in 1886, he was promoted to be Assistant Engineer. During his connection with this Company, he made surveys of its holdings in New York City and Jersey City; superintended the repair of various piers and ferry racks; made plans and superintended the construction of a new pier and freight shed at 35th Street, North River; and of the following structures: The Williamsburg Terminal; the freight shed on Pier 3, Jersey City; car houses at Bayonne, N. J.; ferry structures at Bayonne, and at Port Richmond, Staten Island; and the steam-power, counterbalanced, float bridge at Harsimus Cove, Jersey City. He prepared a paper* for the Society in 1888 describing this float bridge. In September, 1888, he was promoted to be Assistant Supervisor, Division A, and given charge of the main-line yards and terminals between Jersey City and Newark, N. J.

Mr. Bensel resigned from the service of the Pennsylvania Railroad in 1889 to accept a position as Assistant Engineer in the Department of Docks, New York City. As Assistant Engineer from 1889 to 1896, he had charge of works of construction on the North River, including the Laight Street Section of bulkhead or river wall; Pier New 29; the sections of bulkhead walls at Franklin Street and West Washington Market; Pier New 23, and Piers New 14 and 15, for the American Line, which at the time were the most modern piers in the city, with an elaborate double-deck steel shed on Pier 14. The work at Pier 14 embraced a difficult piece of rock removal to a depth of 40 ft. below low water, which was successfully accomplished under his immediate supervision by a Department force. He described this work in a paper entitled "Removal of Rock 40 Ft. below Surface of Water, North River, N. Y.", which has been published by the Society.†

In 1896, he left the Department of Docks to become a member of the firm of Steers and Bensel and, for two years, conducted a large amount of dredging and pier construction in and about New York Harbor.

In 1898, Mr. Bensel was appointed Engineer-in-Chief of the Department of Docks, New York City, serving eight years until 1906, when he was made Commissioner of Docks by Mayor George B. McClellan, serving two years, until 1908, when he went to the Board of Water Supply as President.

Many notable works and improvements were initiated or carried out by Mr. Bensel during the time he served as Engineer-in-Chief and Commissioner

* *Transactions*, Am. Soc. C. E., Vol. XIX (1888), p. 309.

† *Transactions*, Am. Soc. C. E., Vol. XXXII (1894), p. 231.

of the Department of Docks, among which were the nine double-deck piers and sheds of the Transatlantic Steamship Terminal on the North River, known as the "Chelsea Section;" the extensive group of very long piers in South Brooklyn; the retaining wall enlargement of Riker's and South Brother Islands; extensive bulkhead wall and pier work on the North and East Rivers; and the construction of all the municipal ferries, consisting of four elaborate steel ferry-houses, eleven slips, and eight of the largest ferry-boats in New York Harbor.

During 1905 and 1906, while Engineer-in-Chief, he acted as Consulting Engineer on an extensive bulkhead wall project in Philadelphia, Pa., for the Girard Estate, for which his services were sought on account of his long experience with this difficult phase of construction in New York City.

Bulkhead wall construction, particularly around Manhattan, presenting many unusual problems in foundation work and involving, as it did, the expenditure of comparatively huge sums of money, had long been studied by boards of engineers and had constantly given concern to the engineers of the Department of Docks. Perhaps the study of this great problem, to which as Assistant Engineer, and, later, in control, Mr. Bensel gave the most lively interest, and which resulted in an adequate design at reduced cost, is a feature which will always link his name with the work of the New York Dock Department. Briefly, this 16-year period of his life was one continuous study to accomplish something worth while by leaving the beaten paths, and to do this, he in no way spared himself or his own comfort. It has been said that Mr. Bensel made more dock history for the epoch during which he was Engineer-in-Chief and Commissioner than any other individual for a similar period of time. He never believed in sacrificing money for a city improvement that was not in full keeping with the standard New York should have. He said, "no one appreciates a poor structure or utility."

Mr. Bensel was appointed a Commissioner of the Board of Water Supply by Mayor McClellan on January 31st, 1908, and, on the same day, he was elected President of the Board by the other two Commissioners. He served in this capacity until his resignation on December 31st, 1910, assuming on the following day the office of State Engineer and Surveyor of New York. His services were characterized by his tremendous personal energy, and his administrative ability effectively advanced the work of the Board.

The time during which Mr. Bensel was connected with the Board of Water Supply was a period of great activity, not only in the actual work accomplished, but, also, in the amount and number of contracts awarded. Forty-one contracts representing a construction cost of $54 000 000 were awarded during his term of office, and work to the value of more than $25 000 000 was done. As the contract cost of the first stage of the Catskill Water System for the delivery of at least 250 000 000 gal. per day from the Esopus water-shed was about $100 000 000, it is seen that during these three years contracts were awarded for more than half the work and one-quarter of it was actually done. Several important questions came up and were settled during this time, including the difficult problem of carrying the Catskill Aqueduct across the Hudson River

at Storm King by means of the deep pressure rock tunnel, 1 100 ft. below the water surface. Another problem related to the type of structure for the aqueduct traversing the several Boroughs of New York City. Through Manhattan, The Bronx, and a part of Brooklyn, it was decided, on the recommendation of the Chief Engineer, to use a deep, pressure, concrete-lined rock tunnel instead of the delivery pipes tentatively suggested in the original plan.

At the Democratic State Convention in the summer of 1910, Mr. Bensel was a prominent candidate for Governor of New York State. The Convention did not select him for this office, but nominated him as the candidate for State Engineer and Surveyor, to which post he was elected in the fall of 1910, taking office on January 1st, 1911. He was re-elected in 1912, and thus served two terms of two years each. During his administration, work was actively advanced on the Barge Canal, the main line of which extends from the Hudson River to Lake Erie and which was the most extensive public work ever undertaken by the State of New York. Although work on this improvement had been commenced under previous administrations, 60% of the total amount was performed during his terms of office.

One of Mr. Bensel's greatest achievements in connection with this project was the change in plan which combined Locks Nos. 2 and 3, of the Cayuga-Seneca Canal, at Seneca Falls, thereby increasing about 100% the horsepower available there for commercial purposes.

A Principal Assistant on his staff as State Engineer, writes:

"One of the things which impressed me greatly was the courageous way in which he handled his engineering appointments while State Engineer, which, like many other executive positions in the State service, are very largely of a political nature, and the pressure to appoint engineers to various positions because of their political affiliations is sometimes quite manifest. Mr. Bensel's attitude in handling the appointments was always very pleasing to the members of the profession. A man's standing as an engineer, his qualifications for the particular position under consideration or to be filled, his term of previous service and right to promotion always came first in Bensel's mind, and political consideration as secondary. This is best evidenced by his appointment of deputy and division engineers, and others, who were promoted to appointive positions carrying substantial salaries. In most instances, they were men of different political faith and were entirely unknown to Mr. Bensel previous to his assuming the duties of State Engineer and were appointed entirely on their past record and qualifications for the positions given them."

In 1915, Mr. Bensel opened an office in New York City and, thereafter, until his death, he was engaged as a consultant on many public undertakings, including the proposed hydro-electric municipal power-house at Oswego, N. Y.; the Great Western Gateway Highway Bridge over the Mohawk River, at Schenectady, N. Y.; and the proposed water-front improvements for Jersey City, N. J.

In 1919, he was appointed a member of the Board of Consulting Engineers for the Vehicular Tunnel under the Hudson River at Canal Street, New York City, connecting the States of New York and New Jersey, serving in such capacity until his death. The Chief Engineer has summed up Major Bensel's connection with this great work in the following manner:

"As a consultant, I found him always ready to give me the benefit of his years of experience in public work to such an extent that at times his interest might be said to have been almost paternal—an interest which I found to be most enjoyable and helpful. His advice was particularly helpful when it came to broad matters of policy in regard to which he had had many years of experience in public life, and this experience was a reservoir of the greatest value. Major Bensel, as a consultant, had a perfect understanding of the relationship which he bore to me as Chief Engineer, which contributed in no small part to the pleasant relations which we enjoyed."

At the outbreak of the World War, Mr. Bensel immediately offered his services to the Government and, on May 16th, 1917, he was commissioned a Major in the Engineer Officers Reserve Corps. He was assigned to duty at Norfolk, Va., where he remained until after the close of the war as Consulting Engineer on the port and harbor development at that Base. He was relieved from active duty on January 3d, 1919, after nearly two years' active service, and remained in the Reserve Corps as Major of Engineers until his death. On October 30th, 1919, he was assigned to the command of the 125th Battalion Engineers, a Reserve unit.

Major Bensel died at his summer home, at Bernardsville, N. J., on June 19th, 1922.

He was married on November 11th, 1896, to Ella L. Day, the daughter of Henry Day and Adelaide Scofield Day. Mr. Day came from New England, while Mrs. Day's people were residents of New York City for four generations. Mrs. Bensel and four children, Louise Day, John A. Jr., Evelyn Adelaide, and Henry Day, survive him.

Few of Major Bensel's many friends really knew him, but those who enjoyed this great privilege will realize how difficult it is to portray his character clearly. He was known as an able administrator and a capable engineer, fearless and progressive. Much of his success came from his keen insight of human nature and few possessed his ability to pass quick judgment with accuracy. Impetuous, but always under control, he was firm in his adhesion to first judgments, but was remarkable in his willingness to listen to appeal and argument. Subordinates could always be certain that an opportunity would be granted them to defend their grievances before him, if they desired to do so. One of his characteristics was the extreme openness with which he dealt with superiors and subordinates. Having a high sense of honor and high ideals regarding professional etiquette and public service, he insisted that those who gave him a professional opinion should be qualified by education and experience to do so, and he expected from those associated with him the same loyal service to a cause that he gave himself. His subordinates were frequently surprised to learn of the intimate knowledge he had of the details of the particular project that might be under discussion, and he expected them to have at least equal knowledge of such details and to know the reason for taking each step.

An associate of many years' standing, writes of him:

"In all my experience, I have never known a man who controlled large forces to be held in such high esteem by the laboring men and mechanics

under him. This love and respect did not always come from those who received help, but often after receiving discipline. It was his pleasure to use his power to help the unfortunate to help themselves."

Another friend states:

"An appeal to the heart of John Bensel always received a generous response; indeed too much of his time was spent helping others. No effort on his part was too great when a friend needed aid. This characteristic was made manifest continuously until his death. It mattered little what kind of assistance was needed, he never spared either his energy or his purse to assist a friend."

When informed of Major Bensel's death at its meeting of June 19th, 1922, the Board of Direction of the Society passed the following preamble and resolution:

"The Board of Direction of the American Society of Civil Engineers records with deep regret the death of John Anderson Bensel, Past-President of the Society, who was a member for thirty-seven years, during eleven of which he served on this Board. His death severed strong ties of friendship and has left us with a deep and lasting sorrow.

"As member of this Board of Direction, he brought to its counsels qualities of leadership upon which we were accustomed to rely and which cannot be replaced—a life-long study of the problems of engineering, and an intuitive knowledge of men, a sound and matured judgment, founded upon natural wisdom and long experience. His mental grasp ignored all narrow considerations and reached out to the larger view. His generous nature rejected all selfishness in favor of the common good. His courage was of the quality that never faltered. But perhaps his most striking characteristic was that clear integrity which was not mere honesty, but an unerring instinct of fairness and of right.

"*Resolved:* That the Board of Direction of the American Society of Civil Engineers give expression of their heartfelt and enduring sorrow to Mrs. Bensel and to his children."

Major Bensel was a member of the American Society of Mechanical Engineers, the American Institute of Mining and Metallurgical Engineers, and the Institution of Civil Engineers of Great Britain. He belonged to the Engineers', Lawyers', Union and University Clubs, of New York City, the Fort Orange Club, of Albany, N. Y., the Nassau County (New York) Golf Club, and the Somerset Hills (New Jersey) Country Club. He was a member of All Souls Unitarian Church of New York City.

Major Bensel was elected a Junior of the American Society of Civil Engineers, on September 2d, 1885, and a Member on March 4th, 1891. He was a Director from 1899 to 1901, inclusive, a Vice-President in 1907 and 1908, and was President of the Society in 1910. As Director, Vice-President, President, and Past-President, he served on the Board of Direction for eleven years. In addition to the papers previously mentioned, he was the author of the following papers and reports which were published by the Society: "Observations on Dock Work in New York Harbor";* "Final Report of the Special Committee to Investigate the Conditions of Employment of, and

* *Transactions*, Am. Soc. C. E., Vol. LIV, Part F (1905), p. 3.

Compensation of, Civil Engineers";* "Final Report of the Special Committee on Floods and Flood Prevention";† and "Address at the 42nd Annual Convention, Chicago, Illinois, June 21st, 1910."‡

ARCHIBALD STUART BALDWIN, M. Am. Soc. C. E.§

Died June 26th, 1922.

Archibald Stuart Baldwin was born at Winchester, Va., on September 28th, 1861, a son of Dr. Robert F. and Caroline (Barton) Baldwin. His family originated in Bucks County, England. The first Baldwin settlers in the United States came to New England in 1632 and were all kindred. His American progenitor was John Baldwin, who came to Milford, Conn., with the "New Haven Company". Among this family, Henry Baldwin was Judge of the Supreme Court of the United States, Mathias Baldwin established the famous locomotive works that bear his name, and others have been governors of States, members of Congress, generals of armies, divines, and authors.

Dr. Robert F. Baldwin, Mr. Baldwin's father, was a prominent practicing physician in Winchester until 1861, when he became Colonel of the 31st Virginia Regiment attached to "Stonewall" Jackson's Brigade. He was captured at the Battle of Rommey in 1862 and was confined as a prisoner of war in Fort Chase. After his exchange, he served as a surgeon in the Confederate Army until the close of the Civil War, when he was elected Superintendent of the Hospital for the Insane at Staunton, Va., occupying this position until his death in 1879. He was married to Caroline M. Barton, daughter of the Hon. Richard W. Barton, U. S. Congressman, and six children were born to them.

Archibald Stuart Baldwin was educated at the Shenandoah Valley Academy at Winchester and at the Staunton Military Academy. His desire was to enter the Medical Profession in which his ancestors had been prominent for so many generations, but his father died when he was only seventeen years old, and he found himself in young manhood cut off from paternal advice and sympathies, facing the general prostration of after-war conditions and dependent on his own efforts.

After teaching school for a year, he began his railway career as a Rodman on the Richmond and Allegheny Railroad (now a part of the Chesapeake and Ohio Railway); but in 1880 he entered the employ of the Iron and Steel Works Association of Virginia with which Company he was engaged for three years on railroad and blast-furnace construction and the development of ore mines. The opinion has been expressed by one who knew him well, that his varied experiences in connection with this Company contributed largely toward his subsequent success.

* *Transactions*, Am. Soc. C. E., Vol. LXXXI (1917), p. 1207.

† *Loc. cit.*, Vol. LXXXI (1917), p. 1218.

‡ *Loc. cit.*, Vol. LXX (1910), p. 464.

§ Memoir prepared by a Committee consisting of Charles F. Loweth, President, Am. Soc. C. E., D. J. Brumley, E. T. Howson, and John W. Alvord, Chairman, Members, Am. Soc. C. E.

In 1883, Mr. Baldwin found employment on the extension of the Baltimore and Ohio Railroad into Philadelphia, Pa., as a Draftsman and Assistant Engineer, in which capacity he had charge of the construction of bulkheads and docks on the Schuylkill River. In 1885, he went West to accept a position with the Chicago, Milwaukee and St. Paul Railway Company as Principal Assistant Engineer on the construction of the Missouri River Bridge at Kansas City. The usual migrations of the younger members of the Profession, however, found him after about a year a Resident Engineer on the construction of the St. Louis and Texas Railroad, now a part of the Louisville, Henderson and St. Louis Railroad, where he remained for a short time. On September 1st, 1887, he was appointed an Assistant Engineer with the Louisville and Nashville Railroad and assigned to its development in the mineral district around Birmingham, Ala. Later, he was advanced to Principal Assistant Engineer in the office of the Chief Engineer at Louisville, Ky. He remained in this position until May 31st, 1891, when, feeling that his health required outdoor work, he was transferred to that of Roadmaster on the main line, with headquarters at Elizabethtown, Ky., where he remained for nearly ten years, gradually building up his strength and maturing in experience and character.

On September 1st, 1901, Mr. Baldwin left the service of the Louisville and Nashville Railroad Company to become Principal Assistant Engineer of the Illinois Central and the Yazoo and Mississippi Valley Railroads at Chicago, Ill. He was advanced to the position of Engineer of Construction on May 1st, 1903, and promoted to Chief Engineer on March 20th, 1905. During his service as Chief Engineer of these railroads, the properties went through a period of great development in both construction and maintenance work; numerous branches and auxiliary lines were built, and, on many parts of the line, grades were reduced, alignment was improved, and second track was built, a number of large yards were constructed, terminal facilities at New Orleans, La., St. Louis, Mo., and other places, were enlarged, and the general condition of the roads was greatly improved.

Mr. Baldwin held the office of Chief Engineer of the Illinois Central Railroad until August 1st, 1918, when he was elected Vice-President of the Corporation, which position he held while the railroad was under Federal Control. At the conclusion of Federal Control on March 1st, 1920, he was re-elected Vice-President and was placed in charge of the Chicago Terminal Improvement of the Company.

This improvement was involved with the Chicago Plan, calling for a lake front park skirting the South Side, with viaducts above and subways below the railroad tracks, giving access to it, and for the creation of a harbor district and dock facilities from 16th to 31st Streets, with railroad connections thereto. The Railroad Company's projected improvements include the reconstruction of its terminal north of 51st Street; the building of a passenger station fronting on Roosevelt Road, adjacent to, and in architectural harmony with, the Field Museum of Natural History; the building of a new suburban terminal at Randolph Street; the rebuilding of the South Water Street Freight Terminal; and the electrification of the entire terminal to Matteson, 28 miles south of the Chicago River; and the South Chicago and Blue Island Branches.

These vast projects, requiring years to build, had to be thought out and carefully negotiated among many conflicting interests. Here was a public service of the first order, although apparently done in the line of duty. It took more breadth of view and regard to the public welfare than any narrow conception of corporate interest to conclude this great public benefit to the satisfaction of every one. The negotiations were begun in 1912 between the City of Chicago, the South Park Commissioners, and the Illinois Central Railroad, and, ably supported by President Markham, Mr. Baldwin handled the entire matter for the Illinois Central to its successful conclusion in the Contract Ordinance of July 20th, 1919.

Before arriving at a decision on many important questions arising in connection with the improvement problem, investigation of European electrifications and passenger terminals was deemed to be desirable. Opportunity for such an inspection trip was afforded at the conclusion of the sessions of the Ninth Congress of the International Railway Association, held in Rome, Italy, in April, 1922, which Mr. Baldwin attended as Official Reporter on the subject "Terminal Stations for Passengers". It was while returning from this trip that he died suddenly of heart trouble on a train near Detroit, Mich. The funeral was held at the Hyde Park Presbyterian Church, Chicago, on June 29th, 1922, and interment was at Staunton, Va., on June 30th, 1922.

Mr. Baldwin was a staunch supporter of technical societies, and an active worker in them. Immediately on coming to Chicago in 1901, he became a member of the then newly formed American Railway Engineering and Maintenance of Way Association (now the American Railway Engineering Association), and the heartiness with which he threw himself into the activities of this Association is evidenced by his prominence on its important committees, such as the Committee on Signs, Fences, and Crossings; the Committee on Rail; and the Committee on Stresses in Track. He was also a Director of the Association in 1911, Vice-President in 1914 and 1915, and was honored with the Presidency in 1916, subsequently serving the usual five years as Past-President on the Board of Direction.

Mr. Baldwin became a member of the Western Society of Engineers in 1902. In 1918, he was elected Third-Vice-President, and made Chairman of the Finance Committee and a Member of the Amendments Committee. He was elected President of the Society in 1919, and on assuming this office brought a broad program of increased activities to the attention of the Board and the Society. In this regard, Edgar S. Nethercut, M. Am. Soc. C. E., Secretary of the Society, can best be quoted:

"A development committee was appointed by Mr. Baldwin to consider the problem. On this committee were men experienced in society work and on whose judgment the Board could rely. The recommendation that the society undertake a membership drive was considered at a special meeting of the members of the board, chairmen of committees and active workers. As chairman of this meeting, Mr. Baldwin encouraged the widest discussion, after which he summed up the various arguments and proposals which had been offered, concluding with the recommendation that we undertake such a drive. Through his influence the different points of view were united and the vote finally taken was unanimous. The subsequent enthusiastic support of the

compaign by the members was largely due to his leadership and to his marked ability and uniform courtesy. At the conclusion of the drive the Society was confronted with the problem of assimilating a 200 per cent. increase in membership and to this work, as president and continuing as a member of the Board of Direction and past-president, his thought was most constructive."

Mr. Baldwin was also active in important committee work of the American Railway Association, serving on the Committee on Direction, the General Committee, and the Committee on Third Rail and Overhead Working Conductors of its Engineering Division.

During the World War, he was necessarily tied more closely than ever to the work of his Railway Company. Nevertheless, he found time to serve as a member of the War Board of the Engineering Societies of Chicago, giving freely of his time to that important work. At the suggestion of Engineering Council, he was appointed a member of the Advisory Committee of the Federal Board of Surveys and Maps in 1920.

In addition to the societies mentioned previously, Mr. Baldwin was affiliated with a number of other societies and clubs, including the following: Society of Cincinnati of the State of Virginia, American Railway Guild, Franklin Institute, Chicago Engineers' Club and the Flossmoor Country Club. He was also an Honorary Member of Tau Beta Pi.

Mr. Baldwin was raised in the Protestant Episcopal Church, but, later, became a member of the Presbyterian Church, of which his wife was a member, and of which he was a faithful and devoted attendant and adherent. At the time of his death, he was a member and Elder (since April, 1908) of the Hyde Park Presbyterian Church of Chicago, materially aiding the church by his wise judgment and constructive ability. He was also for many years a member of the Board organized to promote and build the Presbyterian Home for the Aged and Helpless. He entered on his duties as Chairman of the Building and Grounds Committee at a time when the plans of the main building in Evanston were being drawn.

Mr. Baldwin's professional labors, spent entirely in building the nation's transportation system, cover a period of more than forty years. It was a life devoted to the common good, with little regard for personal reward. He was intensely interested in upholding the high ideals of the profession with which he had allied himself, as was illustrated in a manner so characteristic of him in an address, "The Engineers' Trust", which he delivered at the Annual Dinner of the Western Society of Engineers* on the occasion of his retirement as President of that Society. His sympathy was particularly with the younger man. This is revealed in a striking manner in an address which he delivered on "The Young Engineer", before the students of the University of Illinois in April, 1918. With his own early experience undoubtedly in mind, he spoke feelingly of the problem of selecting a vocation when age and experience seem inadequate for so important a decision. This address is summed up in the following quotation:

"What is judgment? It is that faculty of mind formed by a combination of education, experience, and character, that guides into understanding of

* *Journal*, Western Soc. of Engrs., March 5th, 1920.

principles involved and leads to correct decision. Education is the cultivation of inherent powers by discipline and instruction. Experience is another form of education which comes from actually doing and seeing, and is often so persistently repeated as to cause automatic action of mind without process of thought, and is valuable because of its sureness, but when repeated beyond a certain point has no further educational advantages.

"Character is the resultant of the forces of the mind, the spirit, and the body. The spirit is the God-like portion of a man, and the condition of the body is of no small importance for weakness or ill health, in addition to incapacitating, may often times cause a lack of boldness in seizing a psychological moment.

"This judgment becomes the most valuable possession of the individual, and the net result of attainment will be largely governed by the measure of its growth."

Of all Mr. Baldwin's personal qualities perhaps the one which was most outstanding was his modesty. One is often compelled to admire ability in men who fully appreciate it themselves. Often, again, modesty is worn as if it was an ill-fitting garment, obligatory through custom, but compelling unnecessary obscurity. Mr. Baldwin's modesty was innate and unconscious. It expressed itself in the atmosphere he created without his knowing anything about it. It came out of the heart from the culture of generations. There is nothing about a man so lovable to men as this unconscious modesty.

Among his papers found after his death was a pocket notebook in which, among engineering data, he had copied the following quotations:

"To set an example of abstinence from petty personal controversies, and of toleration for everything except lying."

* * * * * * * *

"To be indifferent as to whether the work is recognized as mine or not as long as it is done."

* * * * * * * *

"Never let a man imagine that he can pursue a good end by evil means without aiming against his own soul; any other issue is doubtful; the evil effect on himself is certain."—SOUTHEY.

* * * * * * * *

"If thou art worn and hard beset
With sorrows that thou wouldst forget;
If thou wouldst read a lesson that will keep
Thy heart from fainting and they soul from sleep,
Go to the woods and hills: No tears
Dim the sweet look that Nature wears."

* * * * * * * *

"E'en as he trod that day to God, so
Walked he from his birth,
In simpleness and gentleness and
Honour and clean mirth."—KIPLING.

On December 19th, 1883, Mr. Baldwin was married to Miss Martha Grazier, of Staunton, Va., who, with one daughter, Katherine M., and three sons, Robert F., Howard F., and W. Frazier, survives him. He is also survived by two sisters, Mrs. Hugh C. Preston and Mrs. Barton Myers, and three brothers, Robert Frederick, William Barton, and John M., all of Norfolk, Va.

Mr. Baldwin was elected a Member of the American Society of Civil Engineers on December 6th, 1905. He served on the Committee which worked

out the new Constitution that was adopted by the Society in 1921, on the Nominating Committee, on the Washington Award Commission, and as a representative of the four Founder Societies at the Educational Conference at Montreal, Que., Canada. As a member of the Special Committee to Report on Stresses in Railroad Track of the Society he had much to do with the unusually original and important work of that Committee on this (to the railroads) vital subject. At the time of his death, he was a candidate without opposition for Director from District No. 8.

BYRON HARKNESS BRYANT, M. Am. Soc. C. E.*

DIED JULY 8, 1922

Byron Harkness Bryant, the son of Emory D. and Symanthy P. (Balou) Bryant, was born at Woonsocket Falls, R. I., on July 25th, 1847.

He received his education at Kalamazoo, Mich., and began his engineering work as Rodman with a locating party on a survey for a railroad from Litchfield, Mich., to Fort Wayne, Ind., during May and June, 1867.

During July and August and until September 9 of that year, he served as Head Chainman on the location of the Peninsula Railway from Battle Creek, Mich., to Valparaiso, Ind. From September 9, 1867, to April, 1871, he filled the positions of Rodman, Assistant Division Engineer, and Division Engineer on the construction of the Grand Rapids and Indiana Railway.

From April, 1871, to January, 1872, Mr. Bryant was engaged as Chief Engineer of the Grand Rapids and Holland Railroad and, during 1872, he was Chief Engineer of the Middle Division of the Detroit and Bay City Railroad. From March to August, 1873, he was employed as Locating Engineer on the Atlantic and Great Western Railway, and from August, 1873, to October, 1879, he served as Chief Engineer and Superintendent of the Chicago, Saginaw and Canada Railroad.

Mr. Bryant held the position of Locating and Resident Engineer on the Denver and Rio Grande Railroad from October, 1879, to March, 1884. During this time, he located long sections of the railroad, made numerous explorations, including one through the Grand Canyon of the Gunnison River, out of which the famous irrigation tunnel has been constructed, and also had charge of the construction of 400 miles of road.

From March, 1884, until December, 1885, he was employed as Construction Engineer by the Canadian Pacific Railway Company, in charge of the construction of the line on the Lower Kicking Horse River, down the Columbia River, a section several miles in length over the summit of the Selkirks, and another section through the Gold Range Mountains. From March, 1886, until the end of that year, he held the position of Locating Engineer on the Montana Central Railway.

Mr. Bryant was Chief Engineer, Superintendent, and General Superintendent of the Colorado Midland Railroad, and Chief Engineer of the Busk Tunnel Railway from January 1, 1887, to December, 1904. While in this

* Memoir prepared by Charles Hansel, M. Am. Soc. C. E.

position, he built the Busk Tunnel, 9 400 ft. long, then the second longest tunnel in the world. From December, 1904, to July, 1905, he was Chief Engineer of the Colorado and Eastern Railroad.

His work was not confined to the United States. From July, 1905, to March, 1909, he was Chief Engineer of the São Paulo and Rio Grande Railway, with headquarters at Parana, Brazil. While in this position, he located more than 1 000 miles of line. From Brazil, Mr. Bryant went to Mexico, where he was appointed Chief Engineer of the Mexico-North Western Railway, at Chihuahua, and located and explored several hundreds of miles of line.

Mr. Bryant left Mexico for Central America where, as Chief Location Engineer for the International Railways of Central America, he located projected lines in Guatemala, Salvador, and Honduras.

His great ability as a railroad location engineer was known and appreciated. He was a man of splendid character and ability, tireless in energy, thoughtless of self, always a gentleman, having kept a holy faith in God and his fellow man. His professional achievements were varied and important. Work was his happiness, achievement his compensation; he loved his profession and he was loved by all who knew him.

Mr. Bryant was elected a Member of the American Society of Civil Engineers on September 6, 1910. He was also a member of the Western Society of Engineers.

WALTER LINSLEY COWLES, M. Am. Soc. C. E.*

Died December 4, 1922.

Walter Linsley Cowles, one of three sons of Robert Henry Cowles and Harriet M. (Beadle) Cowles, was born in Wallingford, Conn., on January 7, 1859. His mother was also a native of Wallingford. His father was born in Farmington, Conn., but spent most of his life in Wallingford, where he was engaged in the silverware business. He retired from active work as Treasurer of the Dime Savings Bank of that place. Robert Henry Cowles was seventh in direct line from an ancestor, John Cowles, who came to this country in 1635 and settled in Massachusetts, afterward removing to Hartford, Conn., and then to Farmington, Conn., in 1640.

Walter Linsley Cowles was graduated in 1878 from the Civil Engineering Course at Sheffield Scientific School, Yale University, for entrance to which he had prepared at the Wallingford High School. After his graduation, he became Designing Engineer with the John Clarke Company, Bridge Contractors, at Baltimore, Md. From 1881 to 1883, he was a member of the firm of the Clarke Bridge Company, also at Baltimore, and in 1883 and 1884, he was engaged in the contracting business with A. J. Twiggs and Company, Augusta, Ga. In 1884 and 1885, he served as Bridge Engineer of the Savannah, Florida and Western Railway (Plant System), Savannah, Ga., and, thereafter, until the end of 1886, he was employed as Designing Engineer for the Morse

* Memoir prepared by C. S. Churchill, M. Am. Soc. C. E.

Bridge Company, at Youngstown, Ohio. In 1887 and 1888, he was Engineer with the Atlanta Bridge and Axle Works, Atlanta, Ga., and in 1888 and 1889, he was engaged as Principal Engineer with the King Bridge Company, at Cleveland, Ohio.

From 1890 to 1892, inclusive, Mr. Cowles served as Chief Engineer of the Youngstown Bridge Company, at Youngstown, Ohio. In 1893 and 1894, he was Assistant Manager of the Illinois Steel Company, North Works, Chicago, Ill., and from 1894 to 1898, he was Chief Engineer of the Pottsville Iron and Steel Company, at Pottsville, Pa. From 1900 to 1902, he was employed as Structural Engineer with the Brown Hoisting Machine Company, at Cleveland, Ohio, and from 1903 to 1910, he was Consulting Engineer and Secretary of the D. F. Holman Railway Track-Layer Company. In 1910 and 1911, Mr. Cowles served as Division Engineer, Division of Design, Chicago Passenger Subways, and, in 1912, he was appointed Structural Engineer of the Strauss Bascule Bridge Company. Since 1912, he had served as Structural Engineer of the Mead-Morrison Manufacturing Company, at Chicago.

His business life was that of a Civil Engineer of wide experience in different lines of work, and his life was dedicated primarily to his chosen profession and the happy home life which he enjoyed. In 1917 and 1918, Mr. Cowles took an active part in the Liberty Loan drives, Red Cross, and Y. M. C. A. work, as Secretary of his precinct. He was a member of the Illinois Chapter of the Society of the Sons of the American Revolution, and also of the Western Society of Civil Engineers.

His death, which was due to cancer of the stomach, occurred at his home in Oak Park, Ill., after an illness of nearly four months. The funeral services were conducted at the First Congregational Church of Oak Park of which Mr. Cowles was a member, and he was buried in Forest Home Cemetery.

He was married on February 11, 1891, in Beaver Falls, Pa., to Harriett J. Alford, who, with their daughter Marjorie B. Cowles, survives him. He is also survived by two brothers, Arthur C. Cowles, of Worcester, Mass., and Frederic M. Cowles, of Wallingford, Conn.

Mr. Cowles was elected a Member of the American Society of Civil Engineers on March 6, 1889.

WILLIAM ARTHUR LAFLER, M. Am. Soc. C. E.*

Died January 19, 1922.

William Arthur Lafler, the second son of William Arthur and Ida Anderson Lafler, was born at Gaines, N. Y., on October 22, 1879. He received his college education at the University of Michigan, from which he was graduated in 1903 with the degree of B. S. in C. E.

In July, 1903, Mr. Lafler became Junior Engineer in the United States Engineer Department on surveys, maps, estimates, etc., for a deep waterway from Chicago, Ill., to St. Louis, Mo., and remained on this work until March,

* Memoir prepared by Fred J. Wagner, M. Am. Soc. C. E.

1906, when he went to Monterey, Mexico, as Designing and Constructing Engineer for water-works and sewers. In September, 1906, he entered the Department of the New York State Engineer on Barge Canal work, in charge of surveys and estimates of cost in the vicinity of Rome, N. Y., and, later, as Engineer in Charge of Barge Canal Contract No. 42, in the vicinity of Utica, N. Y.

After leaving the New York State Engineer's Department, Mr. Lafler opened an office in Rochester, N. Y., and did a great deal of work along hydraulic lines. At the time of his death, he was particularly interested in the reclamation of various parts of the Tonawanda Swamp in the western part of New York State.

Mr. Lafler was a man of sterling integrity of character and a high-class engineer. Those of his friends who knew him best were convinced that, had he been granted the usual span of life, he would have made his mark in the engineering field.

He was married on June 11, 1919, to Miss D. Virginia Heath who, with one daughter, Lois Virginia, survives him. He is also survived by his mother and two brothers.

He was a member of Oriental Lodge No. 224, F. and A. M., of Utica, N. Y., and of the Ad. Club of Rochester, N. Y.

Mr. Lafler was elected an Associate Member of the American Society of Civil Engineers on May 4, 1909, and a Member on January 18, 1922, the day before his death.

CHARLES ALBERT LORING WRIGHT, M. Am. Soc. C. E.*

Died August 17, 1921.

Charles Albert Loring Wright, the son of Charles M. Wright, Deputy Chief of Police of Springfield, Mass., and Martha R. Wright, was born on May 29, 1871.

He was graduated from the Springfield High School in 1889 and soon after began his engineering work with the firm of A. B. and A. H. Tower, Mill Architects and Engineers, of Holyoke, Mass., which firm designed and constructed many hydraulic power plants in addition to its work of mill designing.

After a period of service with the firm mentioned, Mr. Wright was employed as Assistant Engineer with the firm of E. E. and E. C. Davis, of Northampton, Mass., which was engaged by the Board of Water Commissioners of Springfield, Mass., to take charge of the work on an additional water supply connected with the water supply system of Springfield, at Ludlow, Mass.

On the completion of this work, Mr. Wright was employed by the City Engineering Department of Springfield, in general municipal engineering work, assuming, at first, the duties of an Instrumentman, after which he was placed in charge of sewer construction, having had the direction of this work for several years under the City Engineer.

* Memoir prepared by C. M. Slocum, M. Am. Soc. C. E.

About 1898, Mr. Wright was placed in charge of the general study of bituminous materials for use in pavements, roadways, and sidewalks, which was continued for some years, together with the supervision and inspection of the sewer construction.

With the growth of Springfield and the requirements of street traffic for new and improved street surfaces, the Street Department, in 1914, found that the time had arrived for the introduction of an asphalt plant at the City Yard, and this required the co-operation of laboratory work and methods.

Prior to this decision, Mr. Wright had shown a great interest in the study of bituminous mixtures for use in street pavements, and, by reason of his skill and practical knowledge, he was detailed to the general charge of the asphalt plant and the laboratory work. His competence in connection with this work was such that he was frequently called to other places for counsel and advice on difficult problems connected with street and road improvements.

Mr. Wright's practical knowledge of street and roadway work, coupled with his social nature, allied him strongly with the activities of the Springfield Automobile Club, of which he early became a member. After a time of general membership, the Automobile Club found that he was well qualified to serve as President of the organization, to which office he was duly elected, and he continued to serve as the active and progessive spirit of the Club until the time of his death. Much of the progessive activity in the affairs of the Automobile Club grew out of his intelligent leadership, and he was always alert for its progress and welfare.

Mr. Wright connected himself in early life with the Masonic Order and attained the Thirty-second Degree, having membership also in the "Bela Grotto."

In 1900, Mr. Wright was married to Lillian Alberta Gordon Forbes, the youngest daughter of Dr. Henry Gordon Forbes and Hannah Elizabeth Meyer Forbes, of Chicopee Falls, Mass., and found a true helpmeet in the refined and cultured association of his wife, who died in 1916.

Mr. Wright's musical talent and his fine voice found expression through his membership in the choir of Christ Protestant Episcopal Church, in which he served for many years. He was also associated with the Hampden County Musical Association.

Mr. Wright was elected a Member of the American Society of Civil Engineers on October 10, 1916.

PERCY MAPES LAU, Assoc. M. Am. Soc. C. E.*

Died September 13, 1922.

Percy Mapes Lau was born at Ortonville, Oakland County, Mich., on December 15, 1883.

He was educated in the public schools of Detroit, Mich., and at Pierce Business College, Philadelphia, Pa. He also studied Civil Engineering at

* Memoir compiled from information supplied by N. W. Strait, Assoc. M. Am. Soc. C. E., and on file at the Headquarters of the Society.

the University of Michigan from September, 1904, to June, 1907. During 1903, Mr. Lau was employed as a Stenographer for the International Mercantile Marine Company of Philadelphia.

From September, 1907, to December, 1909, he held field and office positions on preliminary location and construction work with the San Diego and Arizona Railroad of San Diego, Calif. From December, 1909, to May, 1910, he was employed as Levelman and Draftsman on highway work with the San Diego County Highway Commission.

From May, 1910, to January, 1911, Mr. Lau served as Locating Engineer with the Detroit, Lansing and Grand Rapids Railway Company, of Detroit, Mich., and from January, 1911, to February, 1912, he was employed as Inspector and Bridge Engineer on highway construction with the San Joaquin County Highway Commission, at Stockton, Calif.

In February, 1912, Mr. Lau was appointed Chief Draftsman and Resident Engineer of Division II of the California Highway Commission and held this position until May, 1915. During this time, for a period of six months, he was on temporary leave of absence, acting as Chief Draftsman and Field Engineer for the San Mateo County Highway Commission, of Redwood City, Calif. From May to October, 1915, he also served as City Engineer of Dunsmuir, Calif., during the construction of the concrete State highway through the corporate limits of the city.

In October, 1915, Mr. Lau was appointed Chief Engineer of the Detroit Construction Company, Limited, in charge of the location and construction of the Detroit, Pontiac and Owosso Electric Railway, extending from Detroit to Owosso, Mich., a distance of fifty-four miles. It became necessary to abandon this work owing to conditions prevailing at the time of the World War.

From 1917 to 1919, Mr. Lau was in charge of highway construction approximating \$1 000 000 per year in Oakland County, Michigan, and from 1919 to 1922, he was engaged in the contracting business, during which time he constructed reinforced concrete bridges and approximately forty miles of concrete and gravel highways in Oakland and the neighboring counties.

He was killed in an automobile accident which occurred just north of Pontiac, Mich., on September 13th, 1922.

Mr. Lau was elected an Associate Member of the American Society of Civil Engineers on September 12, 1916.